

Rapid Commercialization Initiative (RCI) Final Report for

Non-Destructive X-ray Examination (NDE) and Non-Destructive Gamma Assay (NDA) of Transuranic (TRU) Waste Drums with

Waste Inspection Tomography (WIT)

**Provided by the
Waste Inspection Technology Company (WITCO)
A Division of Bio-Imaging Research, Inc. (BIR®)**



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NOTICE

This final report is based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. The signatories make no expressed or implied warranties as to the performance of the technology and do not certify that it will always operate at the levels verified. The end user is solely responsible for complying with any and all applicable Federal, State, and other local requirements.

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1. Executive Summary

The Rapid Commercialization Initiative Program

Rapid Commercialization Initiative (RCI) is a component of the Federal Administration's efforts to build cooperative interactions between the private sector, states, and Federal agencies to advance a national environmental solution and bring environmental technologies to market more rapidly and efficiently. As a result of RCI, a Memorandum of Understanding (MOU) was written to accelerate private sector commercialization of innovative environmental technologies and to facilitate regulatory acceptance across state and Federal jurisdictions. The desired product of the MOU is multi-state acceptance of innovative environmental technologies, following verification of the performance of those technologies.

The MOU was signed off by the following parties on August 14, 1995:

- Department of Commerce (DOC)
- Department of Energy (DOE)
- Department of Defense (DoD)
- Environmental Protection Agency (EPA)
- Southern States Energy Board (SSEB)
- Western Governors' Association (WGA)
- State of California Environmental Protection Agency (Cal-EPA)

The MOU resulted in a Federal/state/private cooperative effort (the RCI Program) to expedite the application of new environmental technologies. The RCI Program identifies barriers to the acceptance and use of new technologies and makes use of cooperative demonstration projects to remove these barriers, if possible. The Program includes ten individual demonstration projects, each of which will involve a different environmental technology.

Implementation of the MOU between WITCO/BIR[®] (the WIT technology holder) and the U.S. Department of Energy is authorized by the cooperative research and development agreement (CRADA) number 96-RCI-09 for the WIT technologies. Participating Federal agencies in this RCI project included the Departments of Commerce and Defense, the Environmental Protection Agency, and the U.S. Army Corps of Engineers. Participating states included California, Colorado, Idaho, South Carolina, and Washington. Also participating were the Southern States Energy Board and the Western Governors' Association. The culmination of this effort resulted in the issuance of a technology verification statement which is provided in Appendix A.

Scope of the RCI Project for WIT

The purpose of the project was two-fold. First it was to access the WIT system capability to meet the non-destructive assay (NDA) bias and precision performance criteria which are key performance NDA parameters of the National TRU Program Quality Assurance Program Plan (QAPP) required by the Waste Acceptance Criteria (WAC). Secondly, it was to demonstrate that WIT could be used for the nondestructive x-ray examination (NDE) of TRU drum content.

Technology Description

The mobile Waste Inspection Tomography (WIT) trailer can non-destructively X-ray examine (NDE) and gamma assay (NDA) nuclear waste drums up to 110 gallons in volume and weighing up to 1,600 pounds. These drums can include: low level, TRU, and mixed waste, with light-weight matrices such as combustibles through dense waste such as cement and sludge. WIT includes a 2-MV (million volt) high energy radiation X-ray source and a linear array of 896 channels of solid-state X-ray detectors for digital radiography (DR) which produce an X-ray projection view of an entire drum and computed tomography (CT) which provides slice plane and volume X-ray imaging of drum content. WIT includes two Anger cameras, each with 55 photomultiplier tubes and one sodium iodide crystal to rapidly localize gamma emissions in a drum. Collimated gamma scanning (CGS) provides gamma spectroscopy for isotope identification while active and passive CT (A&PCT) using a high resolution, high purity germanium detector (HPGe), supports the determination of total alpha activity.

Technology Performance

Results confirm that WIT passed the RCI test plan assay bias and precision parameters for all surrogate and actual waste drums that had verifiable known TRU alpha activity. The surrogates and actual drums contained TRU alpha activity amounts known to the project referee except for the sludge drum which turned out not to have a reportable and verifiable result.

WIT also demonstrated that it could be used to produce NDE x-ray image results for qualitatively identifying and verifying drum content (the matrix) relative to previously known content codes.

Technology Status

WIT is nearing commercialization through the sales of transuranic (TRU) waste drum NDE/NDA characterization services to the DOE and its sites with the pending opening of the Waste Isolation Pilot Plant (WIPP). WIT is currently undergoing a DOE-sponsored approval process for the certification of TRU waste drums as a mobile service contractor. This process includes periodic audits and participating in the Performance Demonstration Program (PDP). WIT has also participated in the Capabilities Evaluation Program (CEP) at INEEL. These programs are designed as independent blind testing and verification of performance relative to TRU waste drum NDA characterization.

Technology Limitations

WIT assay throughput during this RCI demonstration was limited to one drum per day on average for a single measurement with limited spectroscopy capability. In a production waste characterization environment this throughput would be unrealistic and slow. WIT requires competitive NDA throughput to be commercially viable. To increase the speed of WIT NDA, WIT will use more gamma detectors to increase NDA throughput on a per drum basis. During

1998, WIT is undergoing an equipment upgrade to increase the number of NDA HPGe detectors to improve throughput and achieve competitive NDA rates.

WIT demonstrated it can NDA a variety of TRU waste drum matrices, including low-density benign matrices like combustibles and high-density sludge. Other demonstration data indicated that WIT NDA minimum detectable amount is 0.1 grams of weapons-grade plutonium. Alpha activity concentrations have been measured by WIT at 220 nanocuries per gram. The National TRU Program (NTP) program minimal detectable concentration requirement needed to allow segregation of low level waste from TRU is 100 nanocuries per gram.

2. Technology Description

Overall Process and Product Description

WIT provides NDE, NDA, and noninvasive volume rendering of nuclear waste drum content. A 2MV X-ray high energy accelerator with a curved linear array of 896 solid-state X-ray detectors is used for digital radiography of an entire drum providing a projection X-ray image to identify drum content. This same accelerator and array of detectors are used for computed tomography which provides thin slice-plane (circular cross-sectional images of a drum) identifying the depth of drum content and distinguishing matrix density variations within the drum. WIT can stack CT slices together and present cut-away cinematic rotating volume rendering (VR) view of drums for noninvasive visual examination. Typical measurement times for WIT X-ray NDE can be 1 minute for a single DR image and 8 to 30 seconds for a single CT slice, excluding drum handling. A typical WIT X-ray imaging pixel size is 1mm while typical WIT X-ray penetration capability is greater than an equivalent of 100 mm of lead. WIT has an 18-bit detector dynamic range designed to image light weight and dense waste (combustibles through sludge) in the same image.

A second detection system consists of two gamma (Anger) cameras each consisting of a single large-area sodium iodide crystal with a high-energy collimator backed by 55 photo-multiplier tubes (PMTs). These gamma cameras are used for 2- and 3-D localization of drum gamma activity with area gamma scanning and single photon emission CT (SPECT) techniques. A typical gamma camera view takes up to 30 seconds, with about 25mm resolution. Gamma spectroscopy data is collected using a WIT technique called collimated gamma scanning to identify the gamma emitting radioactive isotopes. A CGS scan typically requires 30 minutes with a single germanium detector, as was the case with the RCI data. The WIT gamma assay is accomplished via active and passive computed tomography. CGS and A&PCT use a single channel high purity germanium detector and a transmission isotopic source of ^{166}mHo for attenuation correction. WIT A&PCT corrects for energy specific mass attenuation variations three-dimensionally in every individual drum within 50mm voxels (volume elements) to produce an absolute (not pre-calibrated) assay (gram amount) measurement. The typical WIT assay measurement time during this demonstration was nearly 24 hours per drum with a single germanium detector. The technology status section describes WIT's potential for assay speedup with increased NDA throughput.

Other Descriptions (throughput)

Typical measurement time for WIT X-ray NDE can be 1 minute for a single DR image and up to 30 seconds for a single CT slice excluding drum handling. WIT includes a 2 MV high-energy radiation X-ray source and a linear array of 896 channels of solid-state X-ray detectors. For gamma NDA, WIT includes 2 Anger cameras each with 55 photo-multiplier tubes and sodium iodide crystals to rapidly localize gamma emissions in a drum using area emission imaging and single photon emission CT (SPECT) to localize the depth of emission within a drum. A typical gamma camera view requires 15 or 30 seconds each to localize gamma activity within a drum. Using the CGS technique for NDA, WIT identifies the gamma emitting radioactive isotopes. A CGS scan can typically require 30 minutes with a single Germanium detector as was the case with the RCI data. Whereas with multiple detectors, a single CGS scan of a drum could take nearly five minutes. WIT uses A&PCT to quantify fertile isotopes (e.g., ^{239}Pu) with direct measurement of gram amount allowing calculation of total alpha Curie content and thermal power. WIT A&PCT corrects for energy specific mass attenuation variations 3 dimensionally in every individual drum to produce an absolute assay (or gram amount) measurement. The typical WIT assay measurement time for this RCI project was nearly 24 hours per drum with a single HPGe detector. The technology status section describes WIT's potential for assay speedup.

3. Performance

Demonstration Plan

This RCI project was conducted under the terms of a cooperative research and development agreement negotiated between WITCO/BIR (the WIT technology holder) from Lincolnshire, IL, and the U.S. DOE Federal Energy Technology Center (FETC) (the Federal government's RCI co-sponsor and project manager) from Morgantown, WV. BIR (WITCO) provided the WIT technology (trailer) and operations personnel for the demonstration. The RCI team (Table 3-1) participated in the development of the test and evaluation plan that served as the guide for conducting the field activities (Reference 1).

The site used to conduct the demonstration was the Radioactive Waste Management Complex (RWMC) at the U.S. DOE Idaho National Engineering and Environmental Laboratories (INEEL) near Idaho Falls, ID. In February of 1997, 8 sealed 55 gallon TRU waste drums of varying matrices, levels of radioactivity, and TRU isotopic content were X-ray examined and gamma assayed by WIT at RWMC. RWMC provided the real and surrogate blind test drums, facilities, utilities, and personnel needed to support the deployment of the mobile WIT trailer. The drums were handled using a strict chain-of-custody procedure developed by the RCI team appointed referee.

WIT test results were presented to the RCI referee within 24 hours of the testing of each drum and a follow-up summary report on all 8 drums was prepared by BIR and presented to the RCI referee within 10 days following the completion of the last drum.

Table 3-1. Rapid Commercialization Initiative Contacts for the WIT Project

NAME	ORGANIZATION	TELEPHONE NUMBER
Richard Bernardi	Waste Inspection Technology Company A Division of Bio-Imaging Research, Inc.	(847) 634-6425 Extension 114
P. Steven Cooke	U.S. Department of Energy Federal Energy Technology Center	(304) 285-5437
George Schneider	U.S. Department of Energy Idaho Operations Office	(208) 526-6789
Gregory Becker	Lockheed Martin Idaho Technologies Company Idaho National Engineering and Environmental Laboratory	(208) 526-4544
Eric Koglin	U.S. Environmental Protection Agency National Exposure Research Laboratory	(702) 798-2432
James Benetti	U.S. Environmental Protection Agency Office of Radiation and Indoor Air	(702) 798-2330
Wendell Greenwald	U.S. Army Corps of Engineers	(509) 527-7587
Theodore Joy	Southern States Energy Board	(770) 242-7712
Richard Tomlinson	Western Governors' Association	(303) 623-9378
Chester Kawashige	California Environmental Protection Agency	(916) 324-3105
Jake Jacobi	State of Colorado, Department of Public Health and Environment	(303) 692-3036
Charleen Roberts Rensey Owen	State of Idaho, Division of Environmental Quality	(208) 373-0316 (208) 528-2650
Mark Yeager	State of South Carolina, Department of Health and Environmental Control	(803) 896-4251
James Divine Nancy Uziemblo	State of Washington, Department of Ecology	(509) 736-5700 (509) 736-3014

Performance Details

For verification testing, the RCI team referee specified the eight test drums, three surrogates and 5 actual waste drums, nominally representing a cross section of the DOE transuranic waste form configurations. The referee loaded the three surrogates with accurately known radioactive sources and labeled all eight drums with a unique number. The referee and his designates followed chain of custody methods defined in the evaluation plan.

Evaluation criteria and techniques used to assess the WIT performance in the RCI project are founded in the National Transuranic Program TRU Waste Characterization Quality Assurance Program Plan (QAPP), Sections 3.0 and 9.0 Interim Change version, 11/15/96. The QAPP

requires that nondestructive assay characterization facilities intending to generate data for the National TRU Program participate in a Performance Demonstration Program (PDP). The PDP uses blind TRU waste surrogate audit samples to acquire independent performance data used as part of the assessment and approval process for measurement facilities supplying services for the characterization of TRU waste. The precision and bias parameters, criteria, and data analysis used to assess WIT system performance in this evaluation are directly related to those employed in the PDP for the surrogate samples. Alternate data analysis techniques are used for the actual waste form test samples, although the evaluated parameters and criteria are the same. The measurement parameters, performance criteria, and analysis techniques employed in this evaluation are documented in the INEEL Capability Evaluation Project (CEP) Test Plan (Reference 2).

An exception regarding the evaluation of WIT in this RCI project is that replicate measurements of each test drum were not acquired. Precision data derived from replicate measurements are necessary to utilize the evaluation methods of the CEP. To address this situation, precision data acquired from replicate measures during WIT participation in the PDP and CEP programs were used in the RCI evaluation. This allowed the use of the CEP evaluation criteria and techniques thus preserving the integrity of the RCI performance evaluation. The effort to employ governing performance parameters and criteria of the National TRU Program is significant, as it allows ready interpretation of the RCI results relative to that used to approve facilities to characterize waste consistent with WIPP requirements.

Results confirm that WIT passed the RCI test plan assay bias and precision parameters for all surrogate and actual waste drums that had known and verifiable TRU alpha activity. The surrogates and actual drums contained TRU alpha activity amounts known to the project referee except for the sludge drum which did not have verifiable data. WIT NDE results from the three surrogates and five actual waste drums confirmed and verified all drum content codes and matrices. Table 3-2 provides the WIT assay scores that were based on the 24-hour report that followed data collection. The key bias and precision performance parameters are also identified in Table 3-2.

Figure 3-1 is a WIT DR X-ray image of surrogate RCI drum 1SG. It took 60 seconds to acquire the image which consists of 896 pixels across by 900 lines down (each pixel represents about 1mm x 1mm of the drum). This drum contains laboratory glass (e.g., test tubes) in one-gallon polyethylene bottles with Pu standards depicted as the denser objects. This image was acquired at INEEL RWMC in February, 1997. The Pu was loaded into this surrogate drum by the RCI referee and his team. Appendix B includes images from all 8 WIT RCI drums.

Table 3-2. WIT Performance on Measuring Total Alpha Activity

Test Sample ID	Waste Identification Code	WIT %RSD ^a P=pass F=fail	Precision Quality Assurance Objective (%RSD) ^b	Total measured alpha curies (grams ²³⁹ Pu)	WIT % Recovery ^c %R =x/μ P=pass F=fail	% Recovery Acceptance Criteria ^d 95% Confidence Bounds Lower %	% Recovery Acceptance Criteria ^c 95% Confidence Bounds Upper %
1RF	300 (graphite)	7.0 (P)	< 7.0	2.6 (30.0)	127.0 (P)	57.4	142.6
2RF	336 (moist combustible)	2.73 (P)	< 18.0	Below DL	Below DL (P)	43.5	171.5
1SG	440 (glass)	3.89 (P)	< 14.0	0.27 (3.1)	141.4 (P)	32.2	197.8
3RF	442 (Raschig rings)	2.95 (P)	< 14.0	1.2 (13.6)	122.3 (P)	33.1	196.9
2SG	330 (dry combustible)	4.15 (P)	< 14.0	0.13 (1.4)	162.5 (P)	32.5	197.5
4RF	376 (filters/insulation)	1.54 (P)	< 7.0	6.1 (69.4)	86.2 (P)	51.6	148.4
3SG	480 (metals)	4.15 (P)	< 14.0	0.11 (1.3)	179.6 (P)	33.5	196.5
5RF ^e	001 (inorganic sludge)	2.73 (P)	< 7.0	1.9 (21.1)	nonexistent radiation chemistry (unknown)	-	-

a: %RSD obtained from NDA PDP and CEP project replicate data sets, see footnotes 1 & 2.

b: precision QAOs derived from National TRU Program NDA PDP performance criteria

c: %R based on single measurement (% recovery, x/μ, measured value/known value)

d: taken from NTP Performance Demonstration Program (PDP) bias scoring technique

e: unable to evaluate performance due to lack of known drum radioactive material loading

DL=detectable limit, SG= surrogate, RF=real waste originating from Rocky Flats

Footnotes:

1. The WIPP QAPP requires assay precision based on six PDP replicate measurements.
2. The Capability Evaluation Program (CEP) was conducted in October of 1997 at the RWMC at INEEL using a test plan similar to the RCI evaluation plan. The CEP provided sufficient time for WIT to acquire precision data. The project referee identified a subset of drums tested under the CEP with similar physical and radiological content compared to the RCI drums. Under guidance from the RCI team, the project referee incorporated the precision statistics from the CEP and PDP replicate measurements into the RCI verification results.

Other Demonstrations

In addition and subsequent to the RCI evaluation, WIT participated in two inter-comparison NDA test programs sponsored by DOE during October, 1997, also at INEEL RWMC. These programs were called the Capability Evaluation Program (CEP) sponsored by DOE Office of Science and Technology (EM-50), and the Performance Demonstration Program (PDP), sponsored by the DOE Carlsbad Area Office (CAO). The RCI team was not involved with and did not verify the data generated during the CEP or PDP programs. The QAPP bias and precision criteria for total alpha activity (based on direct ²³⁹Pu gram measurements from WIT A&PCT

NDA) were tested in both programs. The PDP involved assaying two drums with 6 replicate measurements each and the CEP involved 4 drums with 8 replicate measurements each with scoring for bias and precision determined relative to total alpha activity for a variety of drum matrices. WIT NDA passed the bias and precision tests for all 6 CEP/PDP drums. Table 3-3 summarizes the October 1997 results for WIT NDA testing of A&PCT at INEEL/RWMC for the 6 CEP/PDP drums.

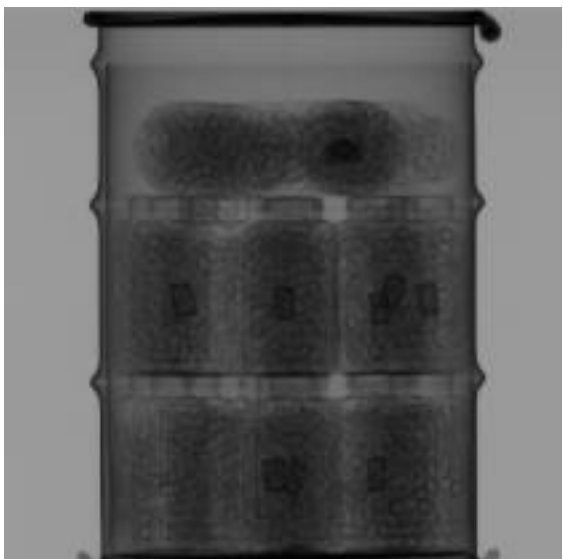


Figure 3-1. WIT 2MV DR of 1SG consisting of lab glass in a 55 gallon surrogate drum loaded with Pu-239. The Pu loadings are imaged as the larger elements within the jars filled with glass tubes. Other WIT RCI imaging results can be found in appendix B of this text.

4. Technology Applicability and Alternate Technologies

WIT is capable of the following NDE and/or NDA inspections:

- Drums or items whose volume is equal to or less than a 110 gallon drum
- Items weighing equal to or less than 1,600 lbs each
- Low level, transuranic, and mixed waste
- All packaging types including metal drums, leaded drum liners, cemented or lead shielding, steel pipe overpacks, metal drum overpacks, poly or fiber board liners, poly drum liners and poly bags
- All matrices including, sludge, cement, metals, glass, plastics, combustibles, etc.
- TRU specified alpha activity levels (except the LLW/TRU threshold)

These types of waste drums can be found at numerous DOE sites including: the Idaho National Engineering and Environmental Laboratory; the Rocky Flats Environmental Technology Site, near Denver, CO; Los Alamos National Laboratory in Los Alamos, NM; Oak Ridge National Laboratory in Oak Ridge, TN; the Hanford Site near Richland, WA; and, the Savannah River Site near Aiken, SC, to name a few.

Technology Alternatives

Non-Destructive Examination Technology

Real-time radiography (RTR) is used to satisfy most NDE needs. A typical RTR unit consists of a conventional, constant current X-ray tube as a radiation source (420-450kV), an image intensifier with an X-ray detection scintillation screen, and video camera with 6 to 8-bits of dynamic range. RTR energies and dynamic range are designed to image lightweight matrices. The main difference between WIT and the RTR systems is the higher energy WIT X-ray source (2MV) and WIT's X-ray detector with 18-bit dynamic range, which is designed to image both dense and lightweight waste matrices.

Non-Destructive Assay Technology

The baseline technologies used to assay drums are gamma spectroscopy and segmented gamma scanning (SGS). The SGS is typically used and is considered the baseline technique with an HPGe detector vertically segmenting a drum for assay. Another gamma NDA system is a tomographic gamma scanner (TGS). There are also neutron-based NDA systems. The main difference between WIT NDA and all of the other NDA systems is that WIT does not require calibration with known matrices and known gram amounts as WIT A&PCT is an absolute direct NDA measurement. All of the other gamma and neutron NDA systems mentioned provide relative measurements and require "acceptable knowledge," with a priori information about the waste to be assayed, in order to calibrate on matrix and gram amount to provide a measurement. WIT does not require acceptable knowledge pre-calibration nor does it provide a relative measurement.

Table 3-3 WIT NDA Test Results for the CEP and PDP Programs at INEEL October 1997

TRU Drum	1	2	3	4a	4b	5	6
Drum ID#	CEPRF-20	CEPSG-6	CEPSG-9	CEPRF-11 ^a	CEPRF-11 ^b	PDP-003	PDP-001
Content Code	480	409	442	003	003	Cycle 4	Cycle 4
Matrix	Leached Metals	MSE Salts	Raschig Rings	Organic Sludge	Organic Sludge	Combustibles	Zero
Net weight kg	109	68	64	140	140	44	0.5
Replicate #	8	8	8	7	7	6	6
Mean Measured ²³⁹ Pu Grams	4.81	47.62	1.41	2.48	2.48	6.77	91.10
% Recovery	96.8	70.7	154.9	161.4	190.9	109.8	99.1
Allowable % recovery range	30.7-199.3	50.9-149.1	33.5-196.5	34.9-195.0	35.9-194.1	33-197	77-123
Precision %RSD	0.8	1.1	4.2	5.0	5.9	2.7	1.5
Max. allowed precision %RSD	14	7	14	14	14	12	3.5
% Total uncertainty	5.1	5.2	6.7	13.7	13.7	5.7	5.2
Bias Test	Passed	Passed	Passed	Passed	Passed	Passed	Passed
Precision Test	Passed	Passed	Passed	Passed	Passed	Passed	Passed

a: evaluation based on INEEL TWCP SAS assay system

b: evaluation based on radiochemistry analysis of sludge samples

5. Cost

Introduction

This cost analysis compares WIT, which is a mobile characterization technology, with two baseline alternatives for non-mobile characterization. Since the circumstances and resources of each site differ, the costs for a non-mobile facility will vary from one situation to the next. This cost analysis attempts to consider the potential range in the non-mobile costs by analyzing two situations: 1) upgrade of an existing characterization facility and 2) construction of a new facility. The WIT technology is approximately 4% more expensive than upgrading an existing facility and 8% less expensive than construction of a new facility. The scope of this cost analysis is limited to the non-destructive characterization functions and does not include costs for drum venting, creating waste shipment documentation, physical examination, or drum loading for shipment.

WIT was demonstrated on a limited number of drums using the vendor's personnel and equipment. This cost analysis is based upon rates quoted by the vendor (analysis assumes the

vendor provides the drum characterization as a service rather than assuming the WIT equipment is purchased and operated by the site) and it includes costs for site personnel who perform drum transfer, quality assurance, and programmatic functions in support of the vendor's operation. The work duration assumes 54 months to process 3,100 m³ of drummed waste (computation of work duration from INEEL Transuranic Waste Project, PLN-129). The observed count/analysis times for WIT were checked against this planned work duration to assure that WIT could keep up with the planned production rates.

The estimates for the two baseline alternatives are generated from the work scope, quantities, and costs identified in: 1) INEEL Transuranic Waste Project, PLN-129 (used as the basis for the upgrade alternative) and 2) Mobile System Plan, DOE/NTP-96-1202 (used as the basis for the new construction alternative). Both the upgrade and the new construction alternatives include costs for construction of surrogate drums, equipment testing and calibration and certification (these costs are assumed to be included in the quoted vendor's rates used in the WIT cost estimate). In both cases, the costs are limited to the non-destructive characterization functions, exclude passive/active neutron costs (so that they match the data available for the WIT), and assume equipment ownership and operation by the site. In the case of the facility upgrade alternative, it is assumed that the segmented gamma scanning equipment and the real-time radiography equipment have substantial upgrades (approximately equal to 50% - 60% of completely new system). The upgrade alternative assumes that the facility will be turned over to some other operation function when the characterization work is completed (similar to the current plans for the Stored Waste Examination Pilot Plant (SWEPP) at INEEL) and no costs for demolition are incurred. The cost analysis for the new construction alternative includes the cost for new equipment, operation, maintenance, construction, and demolition of the facility. But, the construction and demolition costs for this analysis are limited to only the portion of the facility related to the characterization activities (assumes that a facility for drum venting, characterization, drum loading, etc. is constructed but reports only the costs for the walls, floors, electrical, etc. that are specifically for the characterization activity). Based on previous characterization facility planning (DOE/NTP-96-1202), approximately 4,552 m² (49,000 ft²) is required for drum venting, characterization, data processing, management, and drum loading functions. Of the 4,552 m² (49,000 ft²) the portion devoted to non-destructive characterization work is 465 m² (5,000 ft²).

Cost Data

The WIT technology available from WITCO/BIR has associated costs as indicated in Table 5-1.

Table 5-1. WIT Technology Acquisition Costs

ACQUISITION OPTION	ITEM	COST
Equipment Purchase	Trailer and Equipment Maintenance/Warranty	\$3,900,000/each \$450,000/year
Vendor Provided Service (includes crew of 2 operators per shift)	Mobilization (one way) 8 hours/shift Daily Rate 1 shift/day 10 hours/shift Daily Rate 1 shift /day more than one (e.g. 2) shift per day	\$37,000/each way \$9,000/day \$11,000/day actual cost to be determined (estimated at \$12,000/day)

WITCO/BIR service rates for WIT will vary depending upon the overall utilization of the equipment (for example the vendor rates will be lower if the equipment is employed for the entire year and the rates will be higher if the equipment is employed for only a fraction of the year). Additionally, the site will be charged for any idle time (for example the site is charged while WIT is waiting (idle) for drums to be delivered to the WIT trailer). The cost for maintenance is anticipated to be \$4,800 per month (for situations where the vendor's service is used, this is included in the fee). There are additional costs for readiness review, standby, and developing safety, quality assurance and other documentation to satisfy site health and safety requirements.

The work activities considered in this NDE/NDA cost analysis are shown in Table 5-2. Table 5-2 compares WIT costs with two estimated baseline scenarios consisting of an upgrade of the existing RWMC facility and the construction of a new facility at RWMC. The cost estimation was provided by the U.S. Army Corps of Engineers. The projected costs for the two baseline scenarios were based on estimates developed by the Corps.

Table 5-2. Work Breakdown Structure Elements Used in Cost Estimates

WIT Technology	Baseline - Existing Facility Upgrade	Baseline - Construct New Facility
Mobilization (WBS 331.01)	Mobilization	Mobilization
Transport to Site	Relocate Equipment	New Building Construction
Site Documentation Requirements	NDE System Up Grades	Procure & Install Characterization Equipment
Readiness Review		
Characterization (WBS 331.18.90)	Characterization (WB331.18.90)	Characterization
Maintenance/Operations	Maintenance	Maintenance
INEEL Support (Project management, work package management, procedural training, waste handling operations, data validation)	Operation (Including management, implementation, training, waste handling, data validation, scheduling, production assessment, software support, PDP, uncertainty analysis, & calibration)	Operation (Including management, implementation, training, waste handling, data validation, scheduling, production assessment, software support, PDP, uncertainty analysis, and calibration)
Demobilization (WBS 331.21)	Demobilization	Demolition
Vendor Departs Site	Facility Turned Over to Site Next Contractor	Mobilization for Demolition
		Characterization/Survey Building
		Core Sample & Lab Analysis
		Remove Contaminated Equipment
		Package Low Level Radioactive Waste
		Transport Low Level Radioactive Waste
		Spot Decontaminate Floors and Walls
		Demolition
		Segregate, Size and Load Clean Debris
		Haul Clean Debris
		Dispose of Clean Debris
		Demobilize from Demobilization

The following assumptions are common to the cost estimates for WIT and the two baseline technologies. Work is assumed to be performed at INEEL and labor rates are based on standard rates for those crafts. Some costs are omitted from this analysis to facilitate understanding and comparison with costs for the individual site. Consequently, the INEEL indirect expense rates for common support and materials are omitted from this analysis. The overhead and general and administrative (G&A) rates for each DOE site vary in magnitude and their application. Decision-makers seeking site-specific costs can apply their site's rates to this analysis without having to first "back-out" of the rates used at INEEL. The impacts resulting from this omission is judged to be minor because overhead is applied to both the innovative and baseline technology costs. The basic activities being analyzed originate from the *Hazardous, Toxic, and Radioactive Waste Remedial Action Work Breakdown Structure (HTRW RA WBS)* and *Data Dictionary*, USACE, 1996. The HTRW RA WBS, developed by an interagency group, is used in this analysis to provide consistency with the established national standards.

The planning documents used as the basis for the innovative and the baseline cost estimates assumed an average of 20.5 active/passive neutron analyses per day for 184 shifts per year. Other analyses, such as real-time radiography and segmented gamma scanning, have lower production requirements because some of the drums are rejected as they are processed through the active/passive neutron evaluation and thereby are not analyzed by the downstream technologies. Consequently, the production rate required for the segmented gamma scanning (assumed in the planning document (PLN-129) to be last in the process line) is only 18 drums per day. It is anticipated that if the APNEA technology is used ahead of WIT in processing the drums, then that production rate for WIT will be approximately equivalent to the rates assumed for the baseline technology (the APNEA's production rate is approximately 23 drums per day and will identify drums which will be rejected from further analysis). The work scenario that is used in this analysis assumes that the work will span several years. This analysis assumes all costs are in 1997 dollars. Those costs which are from estimates generated from earlier data (from PLN-129 and DOE-1202) are inflated to 1997 dollars using an inflation rate of 4% per year.

From a cost standpoint, the performance related benefits that are offered by WIT are difficult to translate into a cost savings for situations where WIT is a small component of a larger process. In this analysis, WIT's ability to evaluate the drum contents does not translate into a cost savings because the scenarios assume that the operation process, such as performance criteria, data processing, drum rejection criteria, and ultimate drum disposition is not controlled by WIT. Rather, it is assumed that the production rates and schedules are established to match an overall operation. The WIT technology does have the potential for cost savings where the waste processing and shipment operation is optimized around the WIT's operation and capabilities.

The costs shown for this analysis have a substantial amount of uncertainty because of the potential for variation in the assumptions (particularly the overall duration and quantity of waste processed). The throughput can vary over a wide range. Count times for drums having strong sources and a light matrix could be as long as those assumed in this cost analysis. Additionally,

the new construction baseline scenario makes several site specific assumptions that will vary from site to site.

Cost Conclusions

The unit costs per drum for NDE/NDA characterization are summarized below:

WIT	\$671/drum
Baseline Upgrade	\$629/drum
Baseline New Construction	\$711/drum

These unit costs are computed by dividing the total costs shown in Tables 5-3, 5-4, and 5-5 by the number of drums. The costs shown in this analysis do not include markup for overhead, general and administrative costs, secondary technical reviews, and data verification. Secondary technical reviews of data will increase WIT costs by up to 50%. The analysis of fewer drums (for example from small quantity sites) will increase WIT costs by up to 100% depending on drum quantity and WIT utilization as a result of capitalization. All scenarios assume that 22,500 drums will be examined and assayed over 5 years. Also, all scenarios include staff, management, and quality assurance types of costs. The costs for WIT and the two baseline technologies are summarized in Figure 5-1.

Table 5-3. Cost Estimate for Using WIT

Work Breakdown Structure	Units	Unit Cost	Quantity	Cost	Summary
Mobilization (WBS 331.01)					\$86,800
Transport to Site and Setup	Lump Sum (LS)	\$37,000	1	\$37,000	
Site Documentation Requirements	LS	\$30,000	1	\$30,000	
Readiness Review	Each	\$19,800	1	\$19,800	
Waste Characterization for Acceptance (WBS 331.18.90)					\$14,603,600
Maintenance ¹	month	\$4,800	54	\$259,200	
Operation ²					
WIT	Days	\$12,000	990	\$11,880,000	
Support by INEEL	LS	\$2,464,387	1	\$2,464,400	
Demobilization (WBS 331.21)					\$37,000
Transport Trailer from Site to Home	LS	\$37,000	1	\$37,000	
Procurement Cost (3%)					\$366,810
TOTAL					\$15,094,210
Unit Cost (Total Cost \$/22,500 drums)					\$671

1. Project duration is assumed to be 54 months or 4.5 years based on 184 actual working days/year (PLN-129)

2. Assumes 220 potential working days/year, 184 actual working days/year, and 36 idle days.

Table 5-4. Cost Estimate Based on Upgrading Existing Facility

Work Breakdown Structure Element	Units	Unit Cost	Qty	Cost	Summary
Mobilization (WBS 331.01)					\$801,200
Relocate Equipment	Lump Sum (LS)	\$5,300	1	\$5,300	
NDE System Upgrades	LS	\$795,943	1	\$795,900	
Waste Characterization for Acceptance (WBS 331.18.90)					\$13,338,300
Maintenance ¹	LS	\$3,298,600	1	\$3,298,600	
Operation ¹	LS	\$10,039,700	1	\$10,039,700	
Demobilization from Site					
Procurement Cost (3%)					\$8,200
TOTAL					\$14,147,70
Unit Cost (Total Cost \$/22,500 drums)					\$629

1. Project duration is assumed to be 54 months or 4.5 years bases on 184 actual working days per year per PLN-129.

Table 5-5. Cost Estimate Based on Building a New Facility

Work Breakdown Structure	Units	Unit Cost	Quantity	Cost	Summary
Mobilization (WBS 331.01)					\$2,163,600
Construct Facility	m ²	\$18,631	465	\$804,600	
Procure and Install Equipment	Lump Sum (LS)	\$1,359,000	1	\$1,359,000	
Waste Characterization for Acceptance (WBS 331.18.90)					\$13,338,300
Maintenance ¹	LS	\$3,298,600	1	\$3,298,600	
Operation ²	LS	\$10,039,700	1	\$10,039,700	
Demolition (WBS 331.17)					\$438,200
Mobilization for Demolition ³					
Characterize/Radiological Survey	m ²	\$32	1998	\$64,500	
Core Sample & Laboratory Analysis	Each	\$2,419	43	\$104,000	
Remove Contaminated Equipment	m ³	\$369	38	\$14,100	
Package Low Level Rad Waste	m ³	\$293	38	\$11,200	
Transport Low Level Rad Waste	m ³	\$308	38	\$11,800	
Dispose of Low Level Rad Waste	m ³	\$1,342	38	\$51,300	
Spot Decon of Floors & Walls	m ³	\$101	93	\$9,400	
Demolition	m ³	\$91	388	\$35,400	
Segregate Size & Load Clean Debris	m ³	\$109	388	\$42,100	
Haul clean Debris	m ³	\$29	1938	\$55,400	
Disposal of Clean Debris	m ³	\$20	1938	\$39,000	
Demobilization from Site ³					
Procurement Cost (3%)					\$50,763
TOTAL					\$15,990,900
Unit Cost (Total Cost \$/22,500 drums)					\$711

1. Project duration is assumed to be 54 months or 4.5 years based on 184 actual working days/year (PLN-129).

2. The building construction and demolition costs are only for a 465 m² (5,000 ft²) portion of a larger support building (including drum venting, loading, etc.). The 465 m² (5,000 ft²) is the space required for the NDA and NDE drum characterization. The larger support building will be required for the WIT alternate as well as for this baseline, and is not shown in either cost analysis since it is common to both and provides for functions not considered in this demonstration. Some costs are omitted from this analysis (such as the mobilization and demobilization of the construction and demolition equipment) because these costs will be incurred for the larger support building even if the 465 m² (5,000 ft²) characterization increment of space were never constructed.

3. Demobilization is not a new facility cost element.

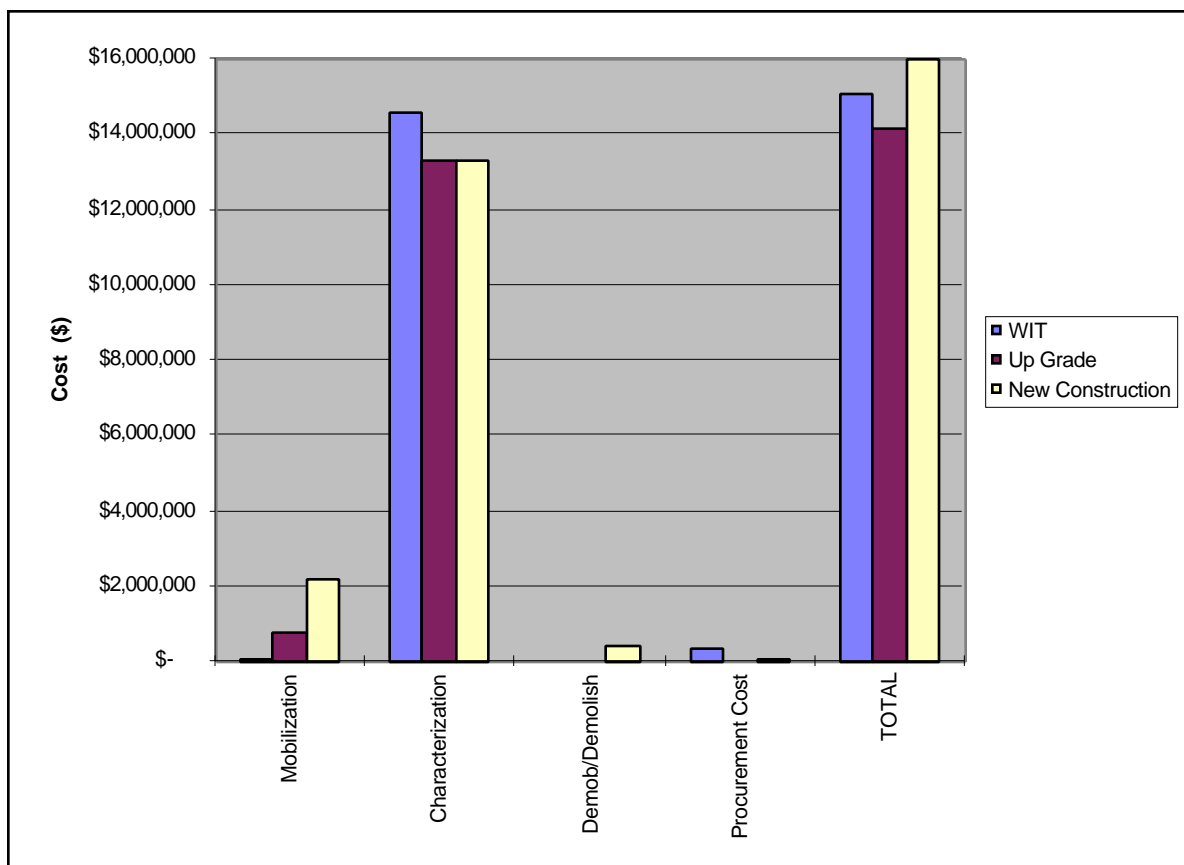


Figure 5-1 Summary of Cost Conclusions

6. Regulatory Policy Issues

Regulatory Considerations

The demonstration of WIT at the Idaho National Environmental and Engineering Laboratory did not require any special permitting requirements at the state or Federal level. There were a number of site specific procedures and policies that had to be adhered to, but these are not expected to be an issue at other sites. The use of radioisotopic sources onboard WIT required that a Nuclear Regulatory Commission (NRC) license be issued. BIR has a State of Illinois license approved by the NRC for sealed isotopic sources each up to 15 mCi in activity. WIT has only one NRC licensable source which is $^{166\text{m}}\text{Ho}$ with an activity of less than 1.5 mCi. WIT currently complies with the BIR State of Illinois license for radioisotopic sources. Relative to the WIT 2MV X-ray source, BIR is required to register this source with the state of Illinois once title and ownership of the WIT system transfers to BIR from DOE. BIR has notified each state that WIT is operating in that a mobile 2MV X-ray source is operating on a specific date or period of time at a specific location and is indeed mobile and temporary. This has typically been done when WIT is operating at a non-DOE or non-Federal site.

State and Federal regulators participated on the WIT project team (Table 3-1). Each regulator was invited to actively contribute during each phase of the demonstration process. A copy of the evaluation plan was provided to each team member for review and comment. The project team members met in Idaho Falls, Idaho in December 1996 to discuss their comments on the demonstration plan. The project team members were also involved in the evaluation of the performance of the system and in the cost evaluation.

During the preparation of this report, there existed a WIPP-related draft Hazardous Waste Act permit from the State of New Mexico. This draft permit describes the baseline NDE technique of RTR as having limited imaging ability with regard to dense drum content matrices such as sludge. The draft permit application states that dense drum matrices shall require invasive visual examination due to the imaging limitations of the baseline RTR NDE technique because contents of dense drums can not be identified using RTR. This demonstration included the successful WIT imaging of dense matrices including sludge with the ability to image the entire drum even through the maximum diameter of the sludge drum with 2MV DR, CT, and volume rendering NDE yielding drum content identification. WIT has demonstrated that it has overcome the limitations of RTR with regard to successful NDE imaging of dense drum matrices and identifying dense drum content as can be seen in Appendix B.

Technology Acceptance

The WIT system does not pose any risks to the community, any individual in the community, nor the environment. The WIT developers have health and safety procedures in place to minimize the possibility of injury to the operators. The issues of concern center on the radioactive sources used in the subsystems and on the hazardous nature of the wastes in the drums being scanned. It is unlikely that the technology will have any measurable economic impact on the community or labor force.

The use of this technology will be primarily affected by the terms of the operating permit issued to the U.S. Department of Energy's Waste Inspection Pilot Plant. The Waste Acceptance Criteria (WAC) Quality Assurance Project Plan (QAPP) contains specific requirements that any technology used to assay and categorize drummed wastes must meet. The acceptance of the WIT as a tool for this purpose is based on whether it meets these criteria. This is not the only application of the technology, but it will be the most common one.

7. Lessons Learned

RCI Program Benefits

BIR entered into the RCI with the intention of demonstrating to DOE regulators that WIT can meet the NDE/NDA requirements of the WIPP WAC for a wide variety of TRU waste matrices. The RCI helped BIR accomplish this goal by providing credible independent verification of WIT performance. BIR intends to use the resulting RCI verification statement as a marketing and sales tool for WIT.

Additionally, BIR and DOE have, through the RCI process, gained a better understanding of the regulatory and technical issues that must be addressed as part of a thoughtful commercialization process. For example, there is a greater appreciation for the difference between demonstration and verification. Verification requires independent scoring of measurement results against known values. And verification requires that the software/hardware/methodology development effort be “frozen” in order to understand the particular configuration whose performance is being evaluated. Furthermore, the RCI team has a better understanding of the roles that demonstration, verification, and certification have in the commercialization process.

Representatives from Federal and state regulatory agencies, because they have been directly involved in the technology demonstration and verification process, have a head start in developing regulatory adaptations to account for the WIT system’s advanced capabilities. For example, the draft hazardous waste permit for WIPP requires lead-lined or dense matrix drums to be visually examined. However, the permit requirement for visual inspection is driven by the limitations of the baseline X-ray technology known as real-time radiography (RTR). WIT’s 2MV X-ray computed tomography system can penetrate lead lined or dense matrix drums, eliminating the need for visual inspection.

Technology Implementation Considerations

The barriers to DOE market entry are summarized in Table 7-1. This table provides the problems and potential solutions observed during this RCI project.

Table 7-1. Perceived Barriers to WIT Entering the DOE Market

WIT Barriers to DOE Market Entry	Potential Solutions
Changing the “Not Invented Here Syndrome” (NIH) through utilization of innovative technology that supports existing site goals and needs where the NIH attitude is rooted in the fear of lose of jobs.	New technology like WIT can be deployed in parallel with existing site capability to save new facility construction costs while utilizing and retraining existing site personnel as WIT operators. Presenting WIT as a supplemental service can effectively increase the site’s NDE/NDA throughput while providing characterization of difficult matrices not achieved with baseline methods.
BIR is not part of the DOE mainstream (i.e., EM-30 or EM-40 or any existing Management and Operation (M&O) or Management and Integration (M&I) contractors).	Transitioning from EM-50 to -30 or -40 requires WIT to participate in credible verification demonstrations, like the RCI, CEP, and PDP programs, to develop EM-30 and -40 White Knights.
WIT exceeds baseline technology capability and may exceed the perceived need for new or better technology	Improved performance over baseline technologies can create market opportunities as long as the performance is verified and using it is cost effective (e.g., WIT NDE/NDA of dense matrices like sludge).
Safety regulations may differ between the NRC, DOE, and various DOE sites.	Cost of market entry for safety will vary from DOE site to site and is the nature of DOE behavior.
Incremental DOE funding on a semi or biennial basis is limiting for small business investments regarding commitments for private capitalization of equipment.	DOE funding methods for innovative, capital intensive technology should allow for 5 years of capitalization in order to promote private investment, especially for small companies who will require five year commitments.
New performance-based contracts at DOE sites may require privatization through new contractors (e.g., M&I contractors) and technologies while decreasing existing contractor roles and responsibilities.	Privatization of NDE/NDA services may require WITCO and BIR to offer a more complete range of services, like providing the certification of DOE waste drums.
The DOE market for TRU drum characterization is poorly defined.	It is centralized at DOE Carlsbad for small quantity sites, it requires individual WIT marketing to the larger DOE sites.

8. References

1. Becker, G.K., APNEA/WIT System Nondestructive Assay Capability Evaluation Plan for Select Accessibly Stored INEL RWMC Waste Forms, Lockheed Martin, Idaho National Engineering Laboratory, INEL/EXT-97-0073, January 1997.
2. Becker, G.K., McIlwain, M.E., Nondestructive Assay System Capability Evaluation Project Test Plan for Transuranic Contaminated Waste Forms, , Lockheed Martin, Idaho National Engineering Laboratory INEEL:/EXT-97-0181, September, 1997.
3. Performance Demonstration Program Nondestructive Assay for the TRU Waste Characterization Program, Scoring Report, September 1997 Distribution, Lockheed Martin Idaho technologies Company, U. S. Department of Energy Carlsbad Area Office, November, 1997.

4. 1996a. Transuranic Waste Characterization Quality Assurance Program Plan. CAO-94-1010, Interim Change, November, 1996, Carlsbad, NM, Carlsbad Area Office, U.S. Department of Energy.
5. Goodman, D., Maximum Likelihood Estimation with Poisson (Counting) Statistics for Waste Drum Inspection UCRL-ID-127361 Lawrence Livermore National Laboratory, May, 1997.
6. Decman, D., Martz, H., Roberson G., and Johansson, E., NDA Via Gamma-Ray Active and Passive Computed Tomography, UCRL-ID-125303, Lawrence Livermore National Laboratory, November, 1996.
7. The National TRU Waste Management Plan, The U.S. DOE Carlsbad Area Office, DOE/NTP-96-1204, Revision 1, December, 1997.
8. Waste Acceptance Criteria for Waste Isolation Pilot Plant, The U.S. DOE Waste Isolation Pilot Plant, DOE/WIPP-089, Revision 5, April 1996.
9. Transuranic Waste Characterization Sampling and Analysis Methods Manual, U.S. DOE Carlsbad Area Office, R-4376, Revision 1, April 1996.
10. Bernardi, R., Field Test Results for Radioactive Waste Drum Characterization with Waste Inspection Tomography (WIT), Proceedings, 5th Nondestructive Assay and Nondestructive Examination Waste Characterization Conference, U.S. DOE Idaho Operations Office, Conf-970126, Salt Lake City, UT, January 14-16, 1997. pp 107-111.
11. INEEL Transuranic Waste Project - Shipment of 3100 m³ of Certified TRU Waste to WIPP, PLN-129, August 1996, Department of Energy, Idaho National Engineering and Environmental Laboratory.
12. Mobile Systems Capability Plan, DOE/NTP-96-1202, September 1996, Carlsbad Area Office, US Department of Energy.
13. Hazardous, Toxic, Radioactive Waste Remedial Action Work Breakdown Structure, and Data, Headquarters United States Army Corps of Engineers, 20 Massachusetts Avenue, NW, Washington D.C., 20314-1000

Appendix A

Rapid Commercialization Initiative Verification Statement for WIT

Rapid Commercialization Initiative

Verification Statement for WIT



Date: August 31, 1998
Technology Name: WIT -Waste Inspection Tomography
Application: Mobile X-ray NonDestructive Examination (NDE) and gamma NonDestructive Assay (NDA) for nuclear waste drum characterization

Technology Type: WIT provides NDE with 2-MV X-ray Digital Radiography (DR) and Computed Tomography (CT) for drum content identification and Gamma NDA with area gamma (Anger) cameras for localization of radioactivity, Collimated Gamma Scanning (CGS) for nuclear spectroscopy, and Active and Passive Computed Tomography (A&PCT) for assay in a single mobile trailer.

Company Name: Waste Inspection Technology Company (WITCO)
A Division of Bio-Imaging Research, Inc. (BIR®)

Company Address: 425 Barclay Boulevard
Lincolnshire, Illinois 60069

Phone: (847) 634-6425 **Fax:** (847) 634-6440, **web:** www.bio-imaging.com **e-mail:** bernardi@interaccess.com

Final Report Title: Rapid Commercialization Initiative (RCI) Final Report for Waste Inspection Tomography (WIT), Report Number: 96-RCI-09, August, 1998
(as a reference)

Environmental Problem Set- The Department of Energy (DOE) has stockpiled in excess of 600,000 Transuranic (TRU) waste drums in retrievable storage at more than 30 DOE sites across the United States. DOE plans to safely and permanently dispose of these drums in a deep geologic salt formation at the Waste Isolation Pilot Plant (WIPP) near Carlsbad, NM. Prior to drum transportation to and disposal at WIPP, regulations from the National TRU Program require noninvasive X-ray inspection with NDE for verification of content (matrix) and NDA for identification and quantification of entrained radioisotopes.

WIT Technology Description- The mobile WIT trailer can X-ray examine and gamma assay drums containing nuclear waste up to 110 gallons in volume and weighing up to 1,600 pounds. These drums can include: low level, TRU, and mixed waste, with light-weight matrices such as combustibles through dense waste such as cement and sludge. WIT includes a 2-MV high energy radiation X-ray source and a linear array of 896 channels of solid-state X-ray detectors for Digital Radiography (DR), which produces an X-ray projection view of an entire drum and Computed Tomography (CT), which provides slice plane and volume X-ray imaging of drum content. WIT includes two Anger cameras, each with 55 photomultiplier tubes and one sodium iodide crystal to rapidly localize gamma emissions in a drum. Collimated Gamma Scanning (CGS) provides gamma spectroscopy for isotope identification while Active & Passive CT (A&PCT), using a high resolution germanium detector, supports the determination of total alpha activity.

Verification Summary - Through a federally sponsored program called the Rapid Commercialization Initiative (RCI), a team of state and federal representatives convened to oversee the demonstration of the WIT technology and verify its performance. The verification objective was to assess the WIT system capability to meet the NDA bias and precision performance criteria which are the key performance NDA parameters of the National TRU Program Quality Assurance Program Plan (QAPP) required by the Waste Acceptance Criteria (WAC). WIT was tested on three surrogate drums with known waste matrices and radioisotopic compositions and five actual DOE generated drums which were independently characterized. Access to surrogate and actual drum alpha activity loading was limited to the project referee; chain of custody forms and non-disclosure agreements were used to protect the integrity of the verification process. The waste matrices ranged from combustibles to sludge, and the isotopic measurements ranged from 0 to 69 grams of ²³⁹Pu (0-6.1 alpha curies). Due to the throughput limitations of WIT (see Technical Limitations), replicate measurements needed for precision analysis were not taken directly on the eight RCI drums and accuracy was calculated using single WIT measurements for each. The precision statistics were obtained from replicate WIT measurements on similar drums under a separate test program (the Capability Evaluation Program or CEP which was not RCI verified). The WIT bias results for the eight drums ranged from 180% to 86% (percent recovery), while precision (relative standard deviation) ranged from 1.5% to 7.0%. WIT assay results met test plan objectives for bias and precision on seven drums. The eighth (sludge) drum assay bias was not verified due to a lack of sludge rad chemistry data for bias comparison. WIT NDE results verified all drum content codes (waste types) and matrices. The three surrogate drum matrices were glass, dry combustibles, and metals. The five real waste drum matrices from DOE included sludge, wet combustibles, graphite, filters plus insulation, and raschig rings. In summary, WIT successfully met the verification objectives of this RCI project.

DEMONSTRATION DESCRIPTION

Test Site - The test site was the Radioactive Waste Management Complex (RWMC) at the U.S. DOE Idaho National Engineering and Environmental Laboratories (INEEL) near Idaho Falls, ID. The RCI test took place in February of 1997. RWMC provided the actual and surrogate test drums, facilities, utilities, and personnel needed to support testing of the mobile WIT trailer. Eight drums were staged at the DOE INEEL site (at RWMC) for this RCI demonstration. The drums were under test plan prescribed control (chain-of-custody) by an RCI team appointed referee and his representatives.

This RCI program was conducted under a Cooperative Demonstration Agreement (CDA) between WITCO/BIR[®] from Lincolnshire, IL, the WIT technology holder, and the U.S. DOE Federal Energy Technology Center (FETC) from Morgantown, WV representing the Office of Environmental Management, Office of Science and Technology (EM/OST). BIR[®] (WITCO) provided the WIT technology (trailer) and operations personnel for the demonstration. The RCI team's participation in the development of the test and evaluation plan (see end note 1) was facilitated through two working meetings (which took place in August and December of 1996 at INEEL) and regular conference calls.

In February of 1997 eight sealed 55-gallon TRU waste drums of varying matrices, TRU radioactivity loading, and isotopic compositions were X-ray examined and gamma assayed by WIT. Test results were presented to the RCI referee within 24 hours of the assay of each drum. A follow-up summary report on all eight drums was prepared by BIR[®] and presented to the RCI referee within 10 days following the completion of the last or eighth drum.

Test Plan Objectives- The RCI program was designed to evaluate WIT NDE and NDA performance relative to selected TRU waste drums. The WIT performance was evaluated per bias and precision criteria derived from the National TRU Program QAPP. (Becker, G., et al, Nondestructive Assay System Capability Evaluation Project Test Plan for TRU Contaminated Waste Forms, September 1997, Number: INEEL/EXT-97-00181, Tables 5 and 6 page 25). The object was to provide an indication of WIT's capability to meet QAPP NDA performance requirements. WIT submitted NDE X-ray image results to qualitatively identify and verify drum content (the matrix) relative to previously known content codes.

The test plan objectives include four ranges of alpha curie content with range specific bias and precision performance criteria. The acceptance criteria represent 95 percent confidence bounds computed per the prescriptions of the National TRU Program PDP scoring procedure. It is recognized that the scope of the test is limited and will not provide all data necessary to completely assess the ability to demonstrate compliance with applicable nondestructive assay requirements and criteria. The test is nevertheless intended to yield capability information regarding key performance parameters which WIT must be able to accommodate.

Technology Elements- WIT provides NDE, NDA, and noninvasive volume rendering of nuclear waste drum content. A 2MV X-ray high energy accelerator with a curved linear array of 896 solid-state X-ray detectors is used for **Digital Radiography (DR)** of an entire drum providing a projection X-ray image to identify drum content. This same accelerator and array

detectors are used for **Computed Tomography (CT)** which provides thin slice-plane (circular cross-sectional images of a drum) identifying the depth of drum content and distinguishing matrix density variations within the drum. WIT can stack CT slices together and present cut-away cinematic rotating **Volume Rendering (VR)** view of drums for noninvasive visual examination. Typical measurement times for WIT X-ray NDE can be 1 minute for a single DR image and 8 to 30 seconds for a single CT slice, excluding drum handling. A typical WIT X-ray imaging pixel size is 1mm while typical WIT X-ray penetration capability is greater than an equivalent of 4 inches of lead. WIT has an 18-bit detector dynamic range (262,144 to one) to image combustibles through sludge in the same DR, CT, or VR image. A second detection system consists of two gamma (Anger) cameras each consisting of a single large-area sodium iodide crystal with a high-energy collimator backed by 55 photomultiplier tubes (PMTs). These gamma cameras are used for 2- and 3-D localization of drum gamma activity with **Area Gamma Scanning** and **Single Photon Emission CT (SPECT)** techniques. A typical gamma camera view takes up to 30 seconds each, with about a 25mm resolution. Gamma spectroscopy data is collected using a WIT technique called **Collimated Gamma Scanning (CGS)** to identify the gamma emitting radioactive isotopes. A CGS scan typically requires 30 minutes with a single germanium detector, as was the case with the RCI data. The WIT gamma assay is accomplished via **Active and Passive Computed Tomography (A&PCT)**. CGS and A&PCT use a single channel high purity germanium detector and a transmission isotopic source of $^{166\text{m}}\text{Ho}$ for attenuation correction. WIT A&PCT corrects for energy specific mass attenuation variations three-dimensionally in every individual drum within 50mm voxels to produce an absolute (not pre-calibrated) assay (gram amount) measurement. The typical WIT assay measurement time for this RCI program was nearly 24 hours per drum with a single germanium detector. The limitations section of this text describes WITs potential for assay increased NDA throughput.

Technology Operating Parameters- For verification testing, the RCI team referee specified the eight test drums. The RCI project designates loaded the three surrogates with accurately known radioactive sources and labeled all eight drums with RCI drum numbers. The referee and his designates followed chain of custody methods prescribed by the specific RCI test plan. WIT test results were presented to the RCI referee within 24 hours of the testing of each drum and a follow-up summary report on all eight drums was prepared and presented by WITCO BIR to the RCI referee within ten days following completion of the last drum.

Verification of Performance- Results confirm that WIT passed the RCI test plan assay bias and precision parameters for all surrogate and actual waste drums that had verifiable known TRU alpha activity. The surrogates and actual drums contained TRU alpha activity amounts known to the project referee except for the sludge drum which has turned out not to have a reportable and verifiable result. WIT NDE results from the three surrogates and five actual waste drums WIT inspected confirmed and verified all drum content codes and matrices previously indicated. The following WIT assay scores were based on the 24-hour report that followed data collection. The QAPP bias and precision requirements which are the key performance parameters are defined in this table. An additional aspect of this RCI process was a cost analysis performed by the U.S. Army Corps of Engineers. The cost analysis compares WIT with baseline activities at INEEL. This cost analysis can be found in the RCI final report referenced on the cover page.

WIT Performance on Measuring Total Alpha Activity

Test Sample ID	Waste Identification Code	WIT %RSD ^a P=pass F=fail	Precision Quality Assurance Objective (%RSD) ^b	Total measured alpha curies (grams ²³⁹ Pu)	WIT % Recovery ^c %R =x/μ P=pass F=fail	% Recovery Acceptance Criteria ^d 95% Confidence Bounds Lower %	% Recovery Acceptance Criteria ^e 95% Confidence Bounds Upper %
1RF	300 (graphite)	7.0 (P)	< 7.0	2.6 (30.0)	127.0 (P)	57.4	142.6
2RF	336 (moist combustible)	2.73 (P)	< 18.0	Below DL	Below DL (P)	43.5	171.5
1SG	440 (glass)	3.89 (P)	< 14.0	0.27 (3.1)	141.4 (P)	32.2	197.8
3RF	442 (Raschig rings)	2.95 (P)	< 14.0	1.2 (13.6)	122.3 (P)	33.1	196.9
2SG	330 (dry combustible)	4.15 (P)	< 14.0	0.13 (1.4)	162.5 (P)	32.5	197.5
4RF	376 (filters/insulation)	1.54 (P)	< 7.0	6.1 (69.4)	86.2 (P)	51.6	148.4
3SG	480 (metals)	4.15 (P)	< 14.0	0.11 (1.3)	179.6 (P)	33.5	196.5
5RF ^e	001 (inorganic sludge)	2.73 (P)	< 7.0	1.9 (21.1)	nonexistent radiation chemistry (unknown)	-	-

a: %RSD obtained from NDA PDP and CEP project replicate data sets, see end notes 2 & 3.

b: precision QAOs derived from National TRU Program NDA PDP performance criteria

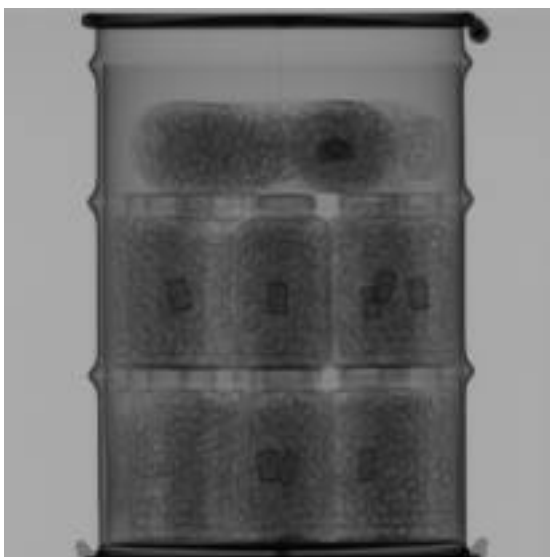
c: %R based on single measurement (% recovery, x/μ , measured value/known value)

d: taken from NTP Performance Demonstration Program (PDP) bias scoring technique

e: unable to evaluate performance due to lack of known drum radioactive material loading

DL=detectable limit, SG= surrogate, RF=real waste, P=pass, F=fail

The following is a WIT 2-MV DR X-ray image of drum number 1SG (glass) which took 60 seconds to acquire and consists of 896 pixels across by 900 lines down where each pixel represents about 1mm x 1mm of the drum. It is presented herein as an example of WIT NDE.



WIT 2-MV DR of 1SG with lab glass and plutonium in a 55-gallon drum

The WIT DR image to the left depicts a surrogate RCI drum (1SG) which contains laboratory glass (e.g., test tubes) in jars with Pu loading indicated as the larger and more dense vials. This image was acquired at INEEL RWMC in February, 1997. The Pu was loaded into this surrogate drum by the RCI referee and his team.

Technical Limitations- WIT demonstrated it can NDE a variety of TRU waste drum matrices requiring 20 minutes per drum resulting in 3 DR and 90 CT images. WIT demonstrated NDE for low-density benign matrices like combustibles and higher-density sludge. WIT assay throughput during this RCI demonstration was limited to one drum per day on average for a single measurement with limited spectroscopy capability. In a production waste characterization environment this throughput would be unrealistic and slow. WITCO/BIR is currently undertaking an upgrade to the WIT trailer to provide for more germanium detectors for improved assay throughput. Other demonstration data have indicated that WIT NDA minimum detectable measurements have been 0.1 grams of weapons-grade plutonium in an interfering matrix. Alpha activity concentrations have been measured by WIT at 220 nanocuries per gram. The NTP program minimal detectable concentration requirement needed to allow segregation of LLW from TRU is 100 nanocuries per gram.

Contacts, RCI Team Members- The WIT RCI team consisted of the co-sponsoring technology holder (WITCO/BIR) the co-sponsoring governmental agency (U.S. DOE FETC), and those governmental agencies that have participated in the verification of the WIT RCI demonstration including:

- Waste Inspection Technology Company (WITCO) , A Division of Bio-Imaging Research Inc. (BIR[®]) from Lincolnshire, IL,
Richard Bernardi (847) 634-6425, extension 114
- U.S. DOE Federal Energy Technology Center (FETC) from Morgantown, WV
P. Steven Cooke (304) 285-5437
- U.S. DOE Idaho National Engineering and Environmental Lab. (INEEL) at Idaho Falls
George Schnieder (208) 526-6789, Greg Becker (208) 526-4544
- U.S. Environmental Protection Agency (EPA) from Las Vegas, NV
Eric Koglin (702) 798-2432, James Benetti (702) 798-2330
- U.S. Army Corps of Engineers from Walla Walla, WA
Wendell Greenwald (509) 527-7587
- The Southern States Energy Board
Ted Joy (770) 242-7712
- The Western Governors Association
Rick Tomlinson (303) 623-9378
- The State of California, Environmental Protection Agency (EPA)
Chet Kawashige (916) 324-3105
- The State of Colorado, Department of Public Health and Environment
Jake Jacobi (303) 692-3036
- The State of Idaho, Division of Environmental Quality
Charleen Roberts (208) 373-0316, Rensley Owen (208) 528-2650
- The State of South Carolina, Department of Health and Environmental Control
Mark Yeager (803) 896-4251
- The State of Washington, Department of Ecology
James Divine (509) 736-5700, Nancy Uziemblo (509) 736-3014

Description of the RCI- Rapid Commercialization Initiative (RCI) is a component of the Federal Administration's efforts to build cooperative interactions between the private sector, states, and federal agencies to advance a national environmental solution and bring environmental technologies to market more rapidly and efficiently. As a result of RCI, a Memorandum of Understanding (MOU) was written to accelerate private sector commercialization of innovative environmental technologies and to facilitate regulatory acceptance across state and federal jurisdictions. The desired product of the MOU is multi-state acceptance of innovative environmental technologies, following verification of the performance of those technologies.

The MOU was made and entered into by and among the following parties: the U.S. Department of Commerce, U.S. Department of Energy, U.S. Environmental Protection Agency, Southern States Energy Board, Western Governors Association, and the State of California Environmental Protection Agency. Concurrence and sign-off of the MOU was completed August 14, 1995.

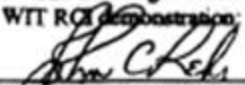
The MOU resulted in a federal/state/private cooperative effort (the RCI Program) to expedite the application of new environmental technologies. The RCI Program identifies barriers to the acceptance and use of new technologies and makes use of cooperative demonstration projects to remove these barriers, if possible. The Program includes ten individual demonstration projects, each of which will involve a different environmental technology.

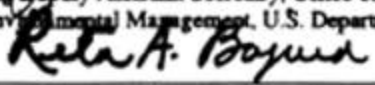
Implementation of the MOU between WITCO/BIR[®] (the WIT technology holder) and the U.S. Department of Energy is authorized by the Cooperative Demonstration Agreement number 96-RCI-09 for the WIT technologies. Participating federal agencies for this RCI include: the Department of Commerce, Department of Energy, Department of Defense, the Environmental Protection Agency, and the U.S. Army Corps of Engineers. Participating States and State Agencies include the Southern States Energy Board, and the Western Governors Association as well as the direct participating states of California, Colorado, Idaho, South Carolina, and Washington.

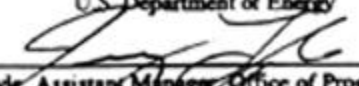
End Notes:


1. This RCI test and evaluation plan reference is: Becker, G. 1997, WIT System NonDestructive Assay Capability Evaluation Plan for Selected Accessibly Stored INEEL RWMC Waste Forms, Idaho National Engineering Laboratory Report INEL/Ext.-97-00073.
2. The WIPP QAPP requires assay precision based on six replicate measurements.
3. The Capability Evaluation Program (CEP) was conducted in October of 1997 at the RWMC at INEEL using a test plan similar to the RCI test and evaluation plan. The CEP provided sufficient time for WIT to calculate precision statistics per the WIPP QAPP requirements using replicate measurements. The project referee identified a subset of drums tested under the CEP with similar physical and radiological content compared to the RCI drums. Under guidance from the RCI team, the project referee incorporated the precision statistics from the CEP replicate measurements into the RCI verification results.

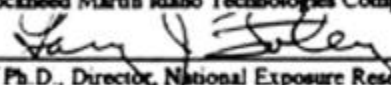
WTT RCI Verification Signatures - The undersigned affirm representatives from their agencies participated in the development and review of the WTT RCI demonstration:

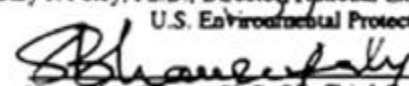

Gerald G. Boyd, Acting Deputy Assistant Secretary, Office of Science and Technology,
Office of Environmental Management, U.S. Department of Energy

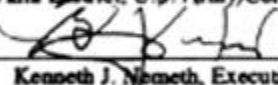

Rita A. Bajura, Director, Federal Energy Technology Center
U.S. Department of Energy

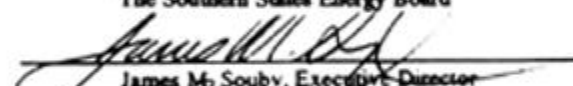

Jerry L. Lyle, Assistant Manager, Office of Program Execution
Idaho Operations Office, U.S. Department of Energy

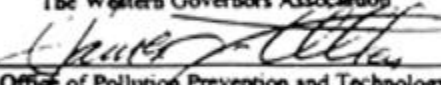

William Guyton, Jr., Vice President, Applied Engineering and Development Laboratory
Lockheed Martin Idaho Technologies Company

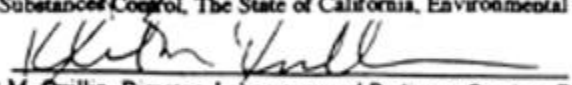

Gary J. Foley, Ph.D., Director, National Exposure Research Laboratory
U.S. Environmental Protection Agency

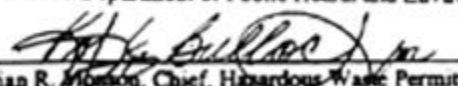

Surya Bharnidipaty, Ph.D., PE, Chief, Engineering Division
Walla Walla District, U.S. Army Corps of Engineers

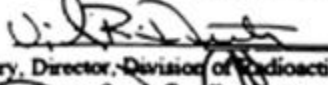

Kenneth J. Nemeth, Executive Director
The Southern States Energy Board

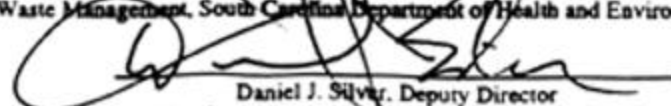

James M. Souby, Executive Director
The Western Governors Association


James T. Allen, Ph.D., Chief of Office of Pollution Prevention and Technology Development, Department
of Toxic Substances Control, The State of California, Environmental Protection Agency


Robert M. Quillin, Director, Laboratory and Radiation Services Division,
Colorado Department of Public Health and Environment


Brian R. Monson, Chief, Hazardous Waste Permitting Bureau
The State of Idaho, Air and Hazardous Waste Division


Virgil R. Autry, Director, Division of Radioactive Waste Management, Bureau of Land
and Waste Management, South Carolina Department of Health and Environmental Control

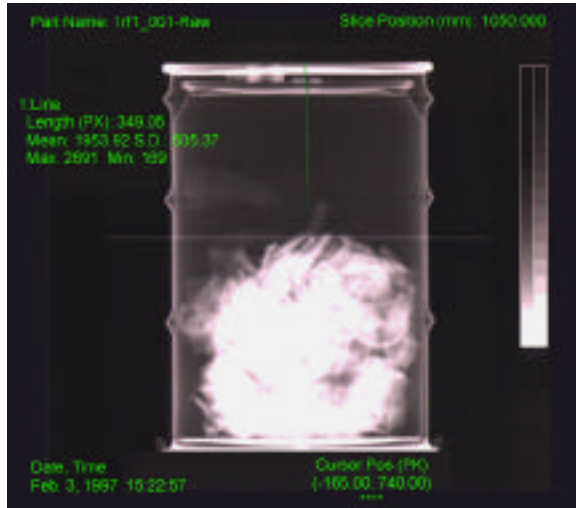

Daniel J. Silver, Deputy Director
The State of Washington, Department of Ecology

DISCLAIMER NOTICE: This verification is based on an evaluation of the technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. The signatories make no expressed or implied warranties as to the performance of the technology and do not certify that it will always operate at the level verified. The end user is solely responsible for complying with any and all applicable Federal, State, and local requirements.

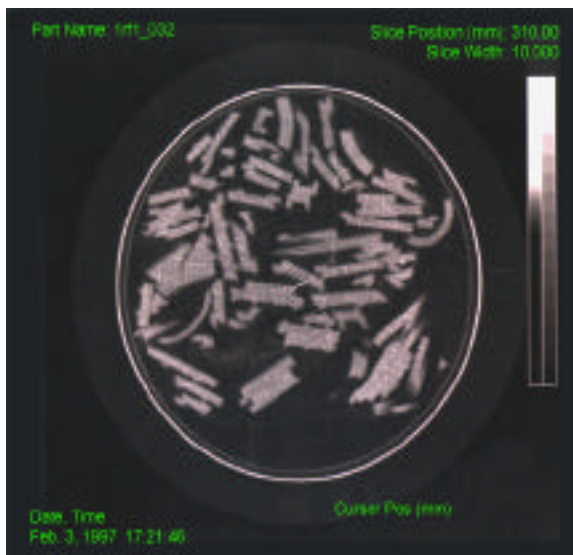
APPENDIX B

WIT RCI Images

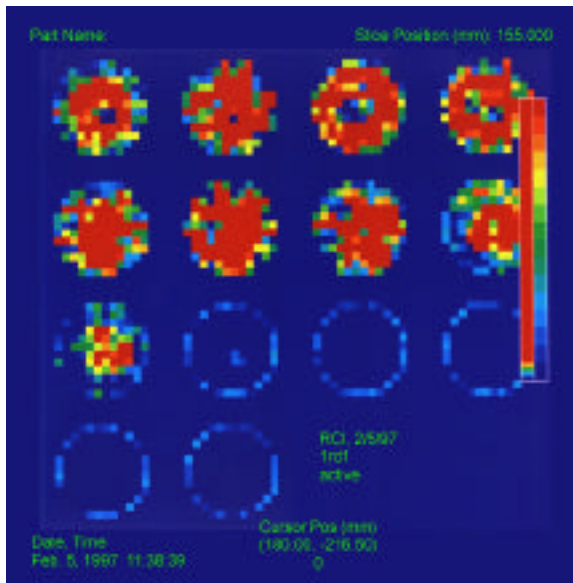
Four WIT Drum Images for each of eight RCI test Drums: DR, CT, PCT, and ACT.



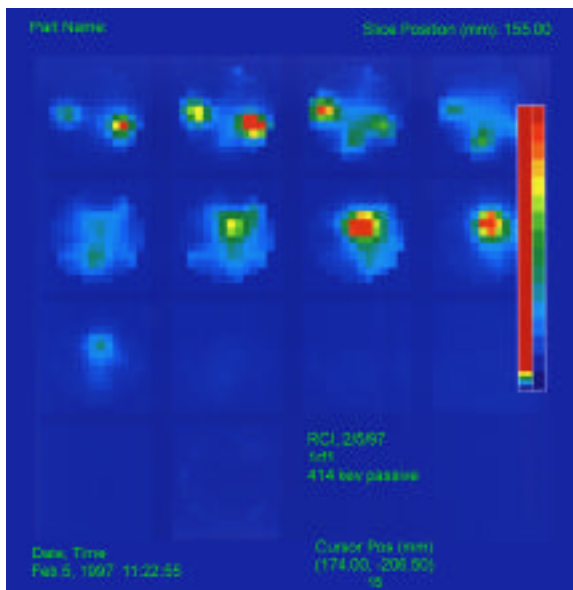
1rf1- WIT 2MV DR of Graphite shapes and pieces in a 55 gallon drum. Note an inner drum liner and greater than a 50% fill height. The poly bag horse tail is also visible



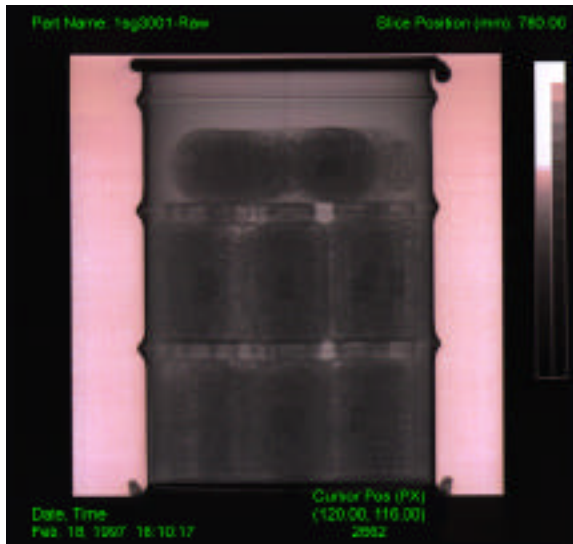
1rf1- WIT 2MV CT of graphite pieces. 10 mm slice thickness Note the poly drum liner is evident just inside the steel drum wall.



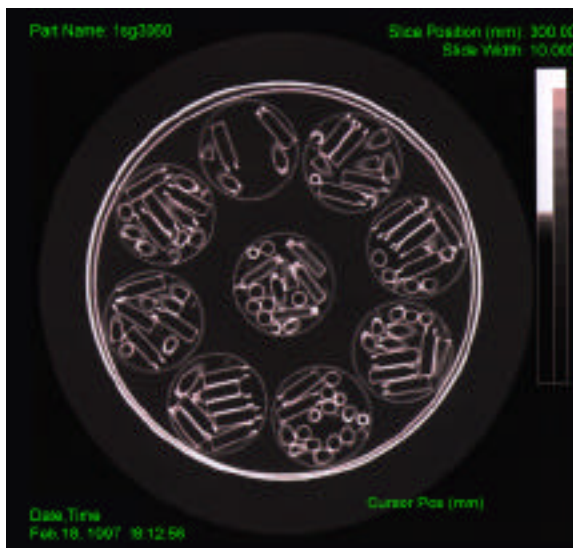
1rf1-Active CT image with 50 mm thick slices starting at the bottom of the drum in the upper left hand corner. This is a map of the mass attenuation of the drum with 50 mm voxel elements. The lower 5 slices represents dead space at the top of the drum.



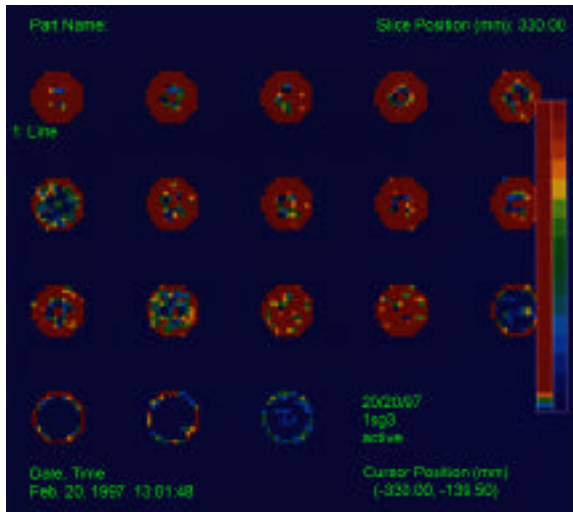
1rf1- Passive CT image at 414 keV showing the "hot spots" of gamma activity in this graphite drum. The bottom of the drum is the slice in the upper left hand corner. Each slice is 50 mm thick and each voxel represents a cube 50 mm on a side.



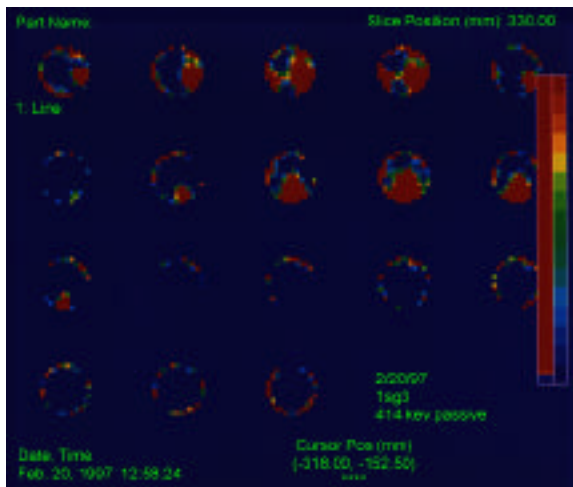
1sg-3 - WIT 2 MV DR of Lab glass loaded with Pu. The lab glass consists of test tubes located in larger jars that are stacked 3 layer high. The top layer of jars are laying horizontal. The Pu loads are evident and are identified as the darker and larger objects in each jar.



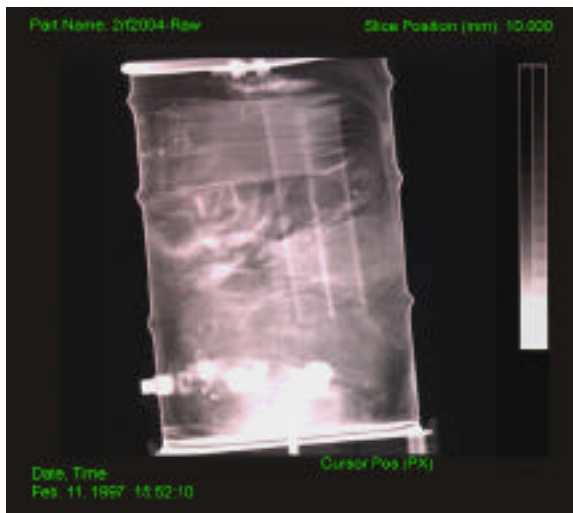
1sg3- WIT 2-MV CT slice of lab glass in jars. Individual empty test tubes are evident. The drum liner is evident as is the 55-gallon steel drum wall. This is a 10 mm CT slice. The Pu loadings are not evident in this slice.



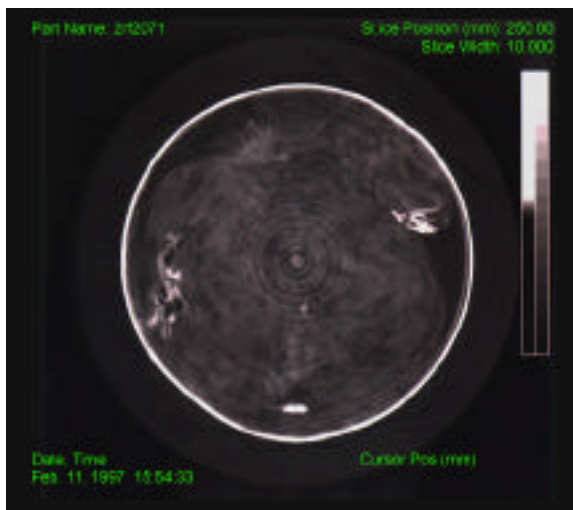
1sg-3 WIT Active CT scan of lab glass. 50mm thick slices. The drum bottom is the upper left hand corner slice. This is a map of the mass attenuation coefficients of the drum. Each voxel is a 50mm cube.



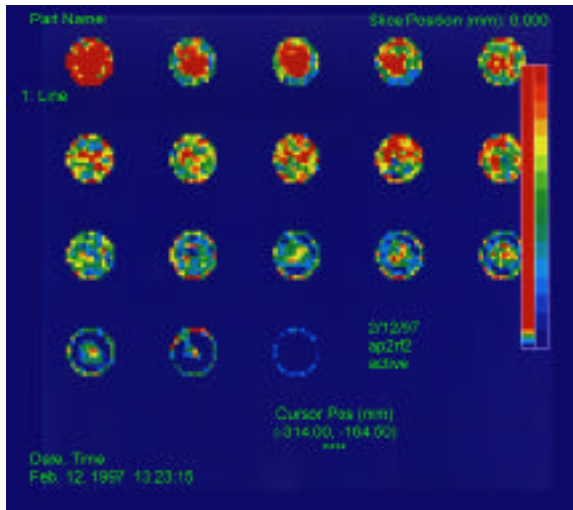
This is a WIT 414 keV passive CT scan of the gamma ("hot spot") activity in lab glass in 1sg3. The bottom of the drum is the upper left hand corner image. Each slice is 50 mm thick.



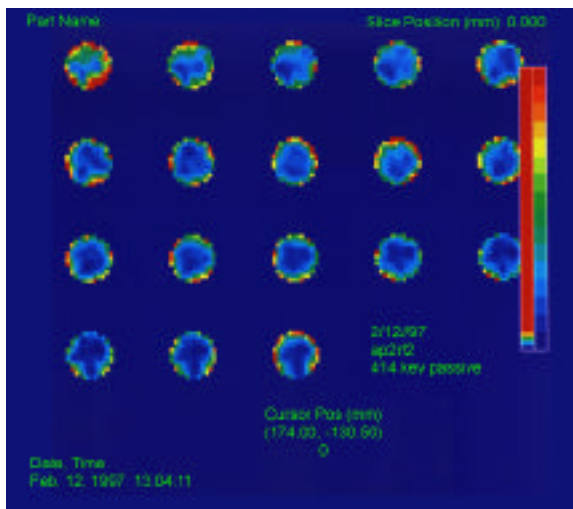
2rf2- WIT tilted 2 MV DR of wet combustibles. This is a 60 second scan with 896 by 900 pixels with a resolution of about 1mm.



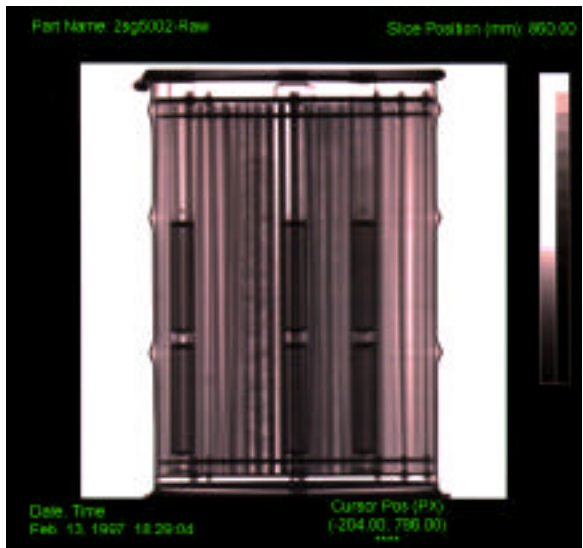
This is a 10 mm thick WIT 2 MV CT slice of 2rf2 which is wet combustibles. High density indications are evident but the majority or greater than 90% of the drum is low density combustibles.



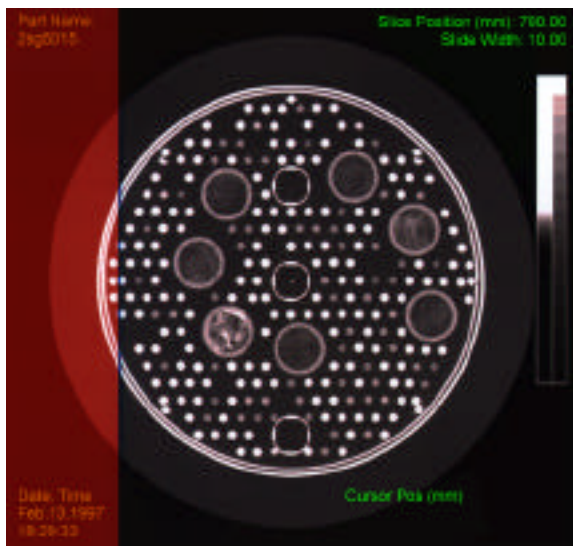
2f2- WIT Active CT of the mass attenuation coefficients of wet combustibles with 50 mm thick CT slices. The bottom of the drum is the upper left hand corner slice.



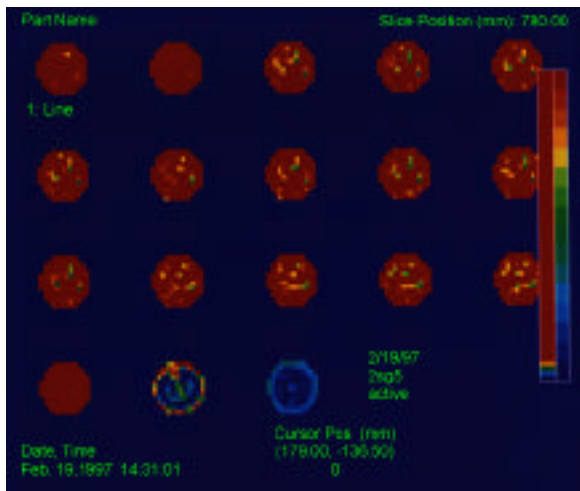
This is a 414 keV Passive CT set of slices showing a **lack** of the gamma (hot spot) activity in the wet combustible 2f2 drum. This drum was found to be below the minimum detectable limit of WIT and indeed had no radioactivity.



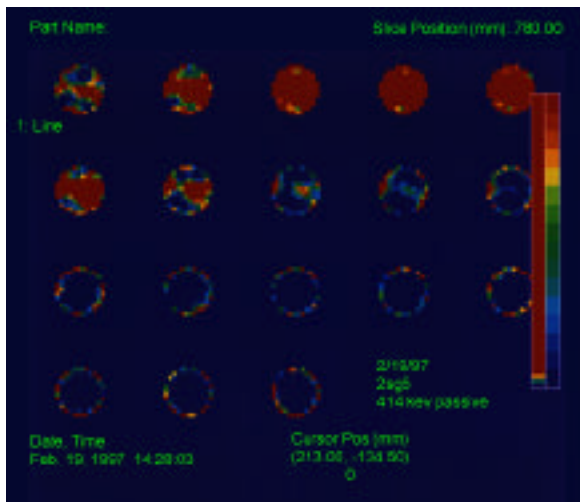
2sg5- WIT 2 MV DR of Dry Combustibles simulated with plastic rods. Metal cylinders containing distributed Pu sources are also evident in a 55 gallon drum.



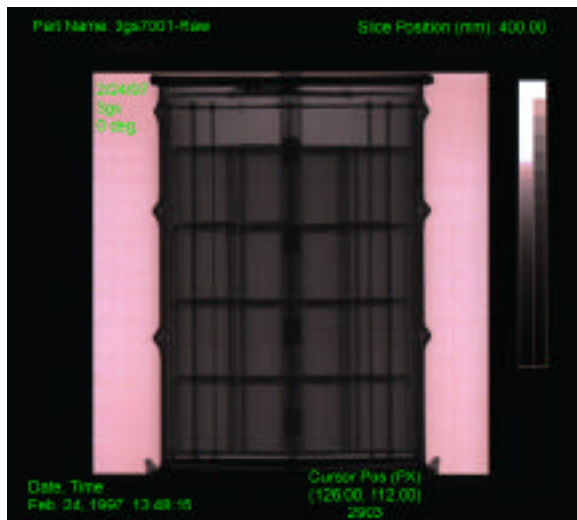
2sg5- WIT 2 MV CT slice of simulated dry combustibles as rods of plastic and other materials. Cylinders are full of various materials which act as radioactive components. The liner is also evident.



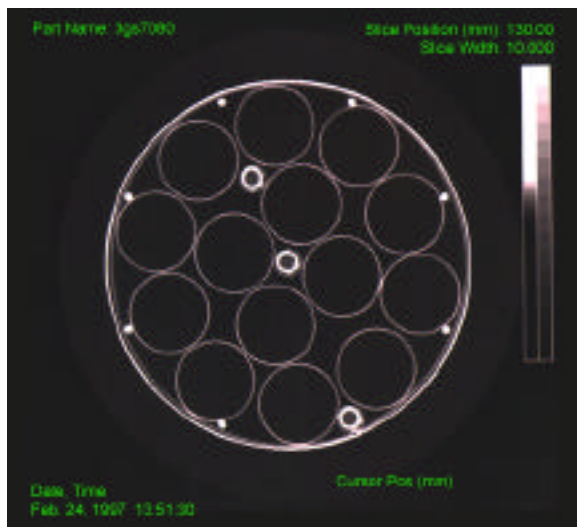
2sg5 active CT of simulated combustibles showing the distribution of the mass attenuation coefficients



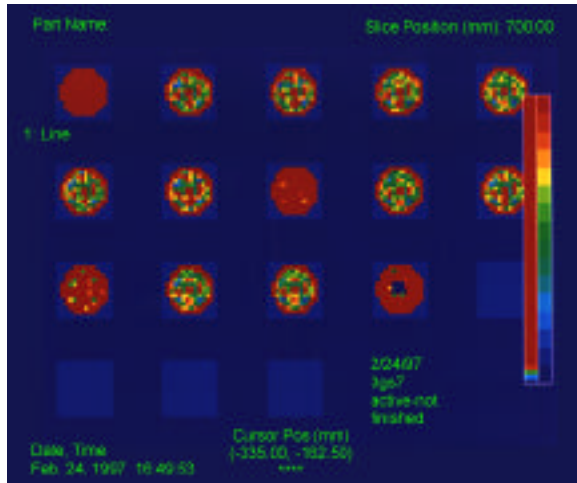
This is Passive CT map of 414keV of 2sg5 showing the gamma hot spots near the bottom of the drum (or the top 7 slices to the left).



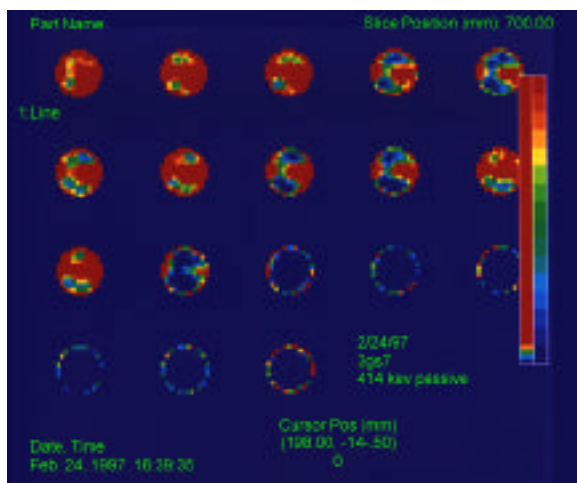
3sg7 - WIT 2 MV DR of metals. Threaded rods are evident as are tubing going down the middle of the drum.



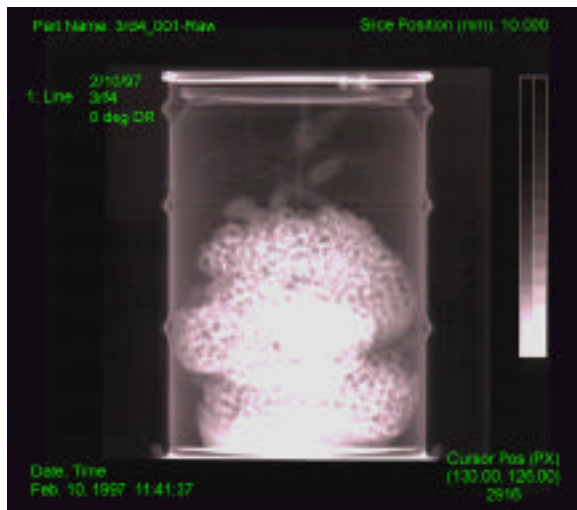
3sg7 - WIT 2 MV CT of metal cans. Threaded rods are evident on the outer inside edge of the drum. Three tubes are evident.



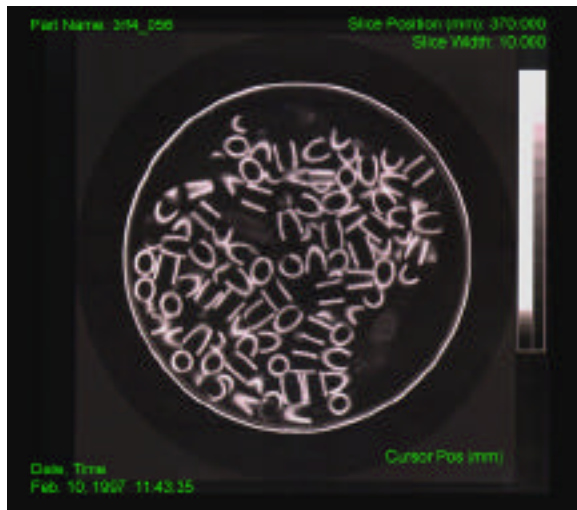
WIT Active CT image set of 3sg7 which is a metals drum full of cans. These images depict the mass attenuation of the drum starting at the bottom which is the upper left hand image. Each slice is 50 mm thick,.



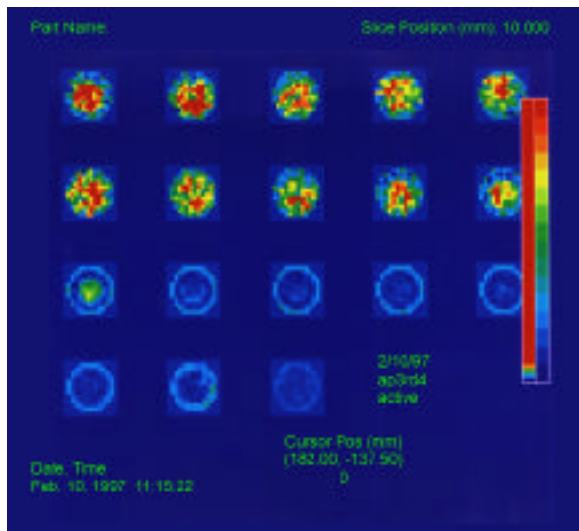
This is a WIT passive CT image set at 414keV which depicts the gamma radioactivity in a drum of metal cans, 3sg7.



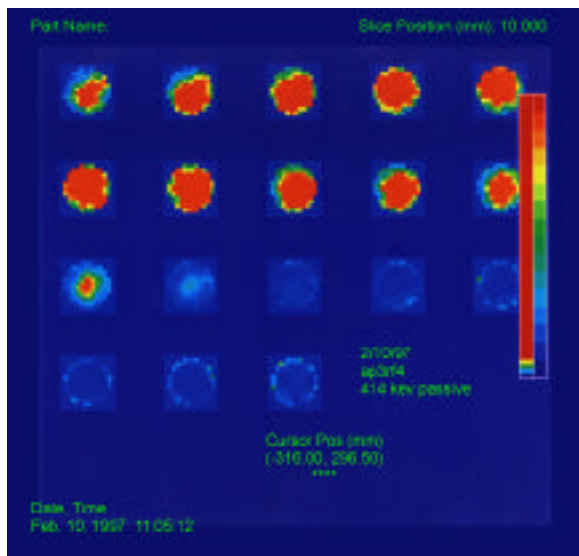
WIT 2mV DR of 3rf4 which is a 55 gallon drum of glass raschig rings. Multiple plastic bags and horse tails are evident as is the drum inner drum liner. The drum is nearly 67% full. This is a 60 second scan with a resolution of 896 by 900 pixels with a resolution of about 1 mm.



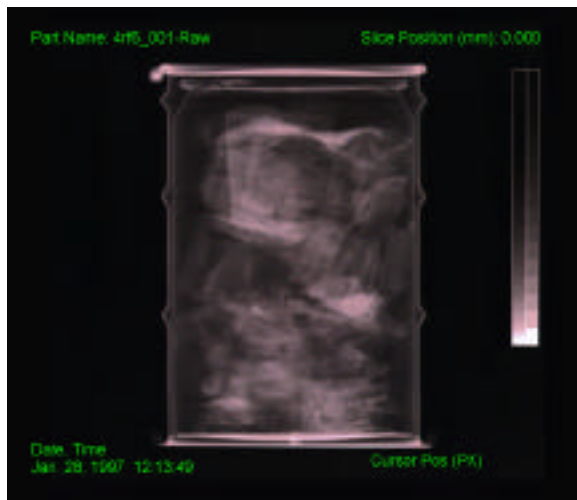
This is a WIT 2 MV CT slice 10 mm thick through 3rf4 which is a 55-gallon drum of borated glass raschig rings which acts as neutron moderators. An individual raschig ring is similar in shape to a single glass napkin ring.



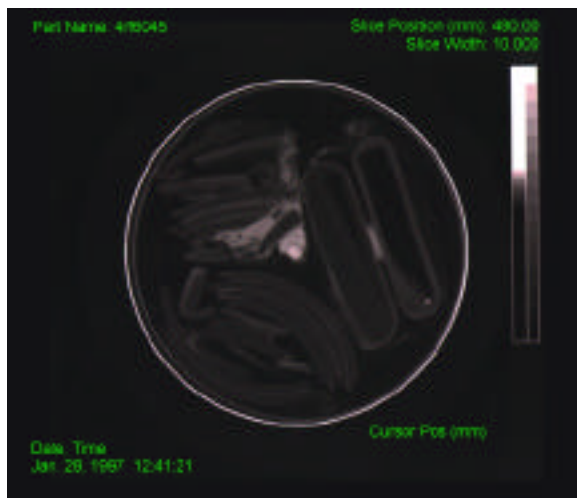
This is a WIT active CT image of 3rf4 which are images of the mass attenuation coefficients of raschig rings. The bottom of the drum is the upper left hand image. Each image is a slice of 50mm thickness.



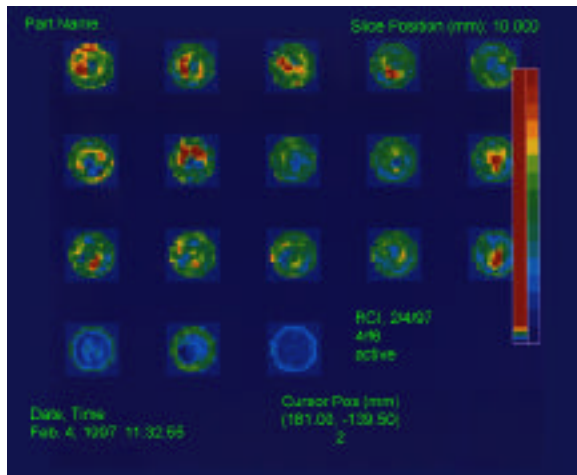
This is a 414 keV Passive CT image of the gamma active hot spots in the 3rf4 drum which is the raschig ring drum.



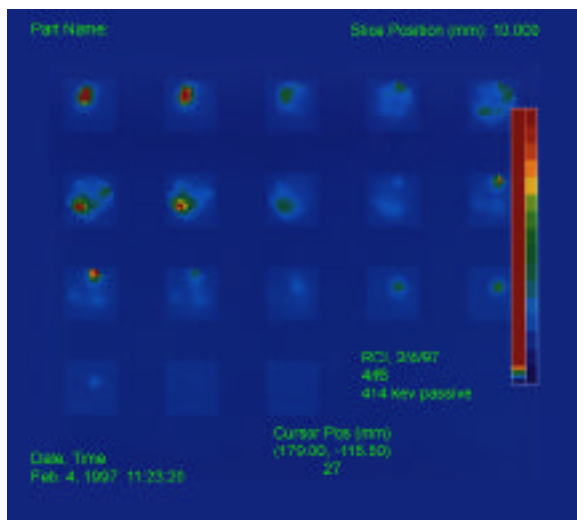
This is a WIT 2 MV DR of 4rf8 which is a filters and insulation drum. The inner liner drum is evident as is the filter shapes. This is also a 60 second scan with 896 by 900 pixels with a resolution of about 1mm.



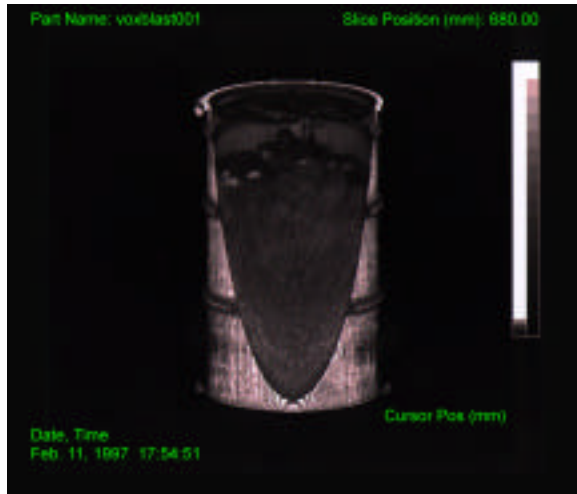
This is a WIT 2 MV CT slice through 4rf8 which is the filters and insulation media. The inner drum liner is evident.



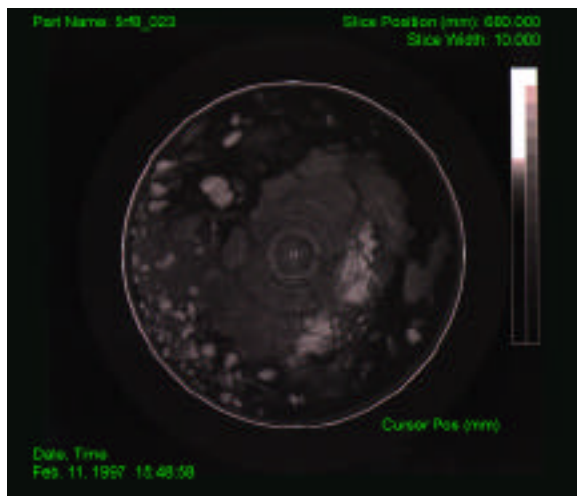
This is an Active CT WIT data set of 4rf8 slices depicting the mass attenuation coefficients in the drum of filters and insulation. The drum is mostly full.



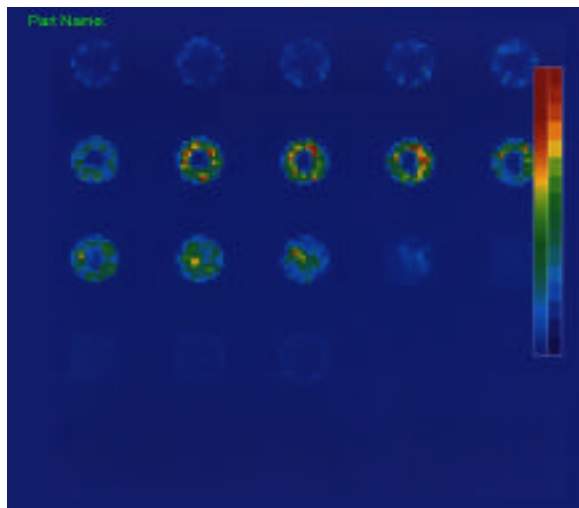
This is a passive CT scan set of 4rf8 which shows the radioactive gamma emitting hot spots in the drum.



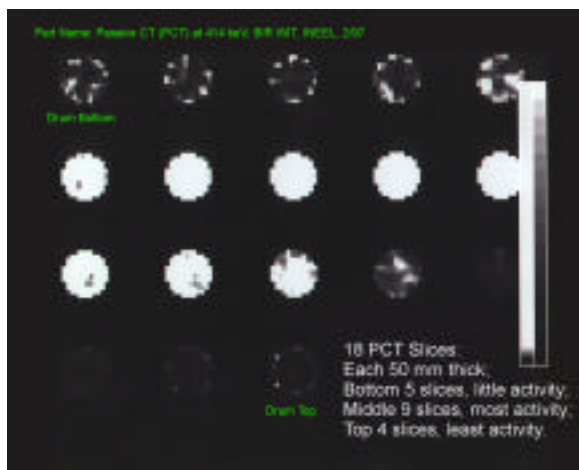
This is 5rf8 and is a WIT CT 3-D volume rendered image made up from 90 10 mm thick 2MV CT slices each taking 30 seconds of scan time. This image is 512 x 512 x 512 pixels with a resolution of about 1mm. The image indicates a more uniform sludge of higher density below the lowest drum rib. Lower density and lumped sludge is indicated above the lowest drum rib.



This is a WIT 2MV CT image of 5 rf8 which is a sludge drum. This is a 10 mm thick CT slice indicating cracking of the sludge.



This is the WIT Active CT map of 5rf8 showing the mass attenuation of the sludge drum.



This is the WIT 414 keV passive CT map of the sludge drum 5rf8. It indicates that the gamma activity is in the upper lower density sludge that physically is more non-uniform based on the x-ray CT. The hotter sludge is above the lowest drum rib. The cold sludge is the lower 5 CT slices shown across the top row of this passive data..